BBC

THE FIRST DIGITAL CREATURE?

HUBBLE'S TOP DISCOVERIES

FOCUS

SCIENCE AND TECHNOLOGY

sciencefocus.com ISSUE 280 / MAY 2015

STRAIGHT FROM THE LAB!

INCREDIBLE INVENTIONS

- Electricity-generating toilets
- Noise-cancelling windows
- Self-cleaning paint

THE REAL TRICORDER

Star Trek-style medical scanners are here!

ALSO

HOW DO WE KNOW THE AGE OF EVERYTHING?

DEADLY MEGA ERUPTION

It killed thousands and cooled the planet. Is it about to happen again?

+

STEPHEN BAXTER: DOES RELIGION HAVE A FUTURE?

25 QUESTIONS ANSWERED

- What's the loudest sound?
- How did zebras get stripes?
- Do fingerprints change?

WHY DOGS COMMUNICATE

TOP 10 MOST COMMON PHOBIAS REVEALED

TESTED: THE NEXT IPOD

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GERARD BUTLER FOR BOSS BOTTLED
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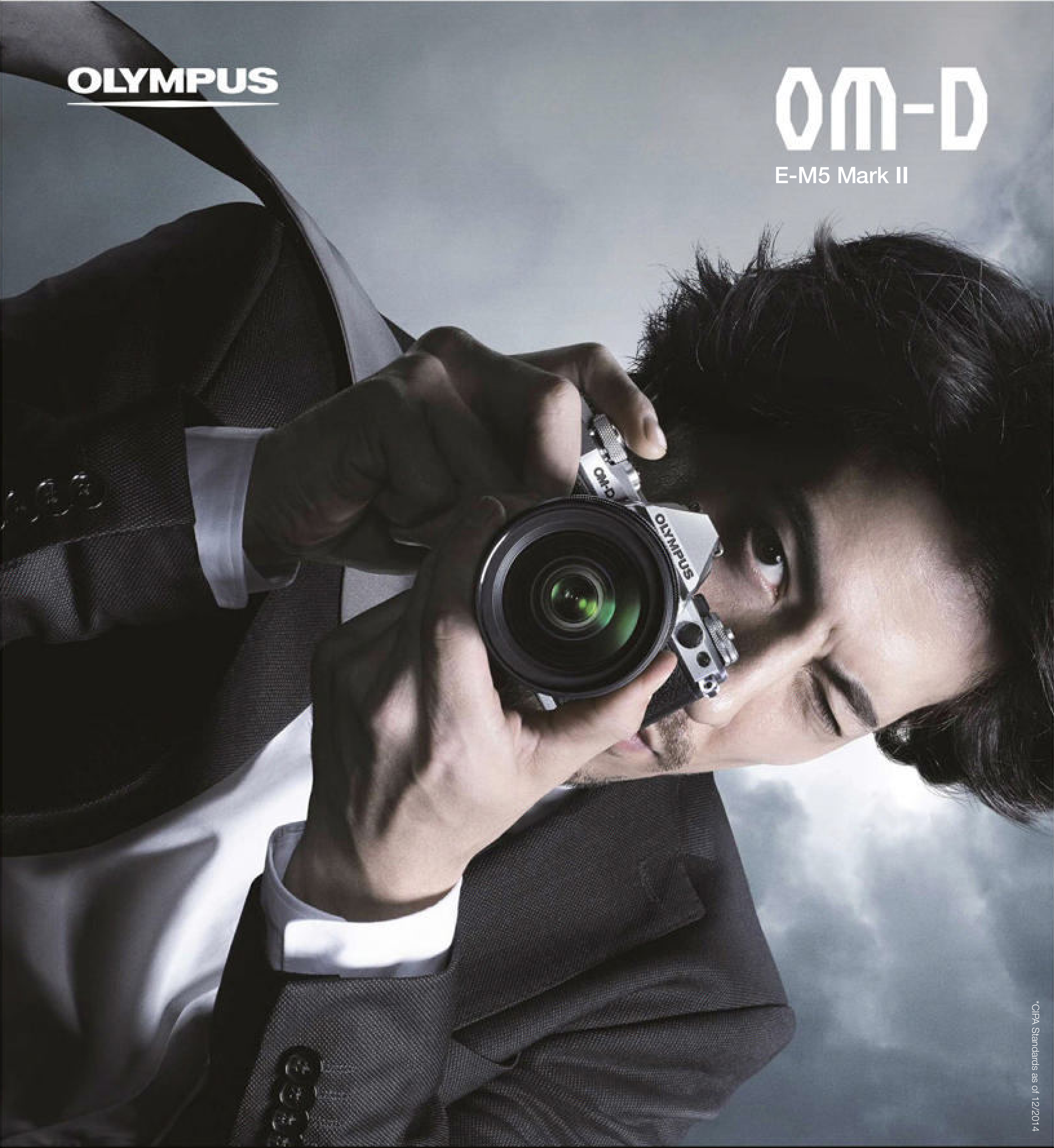

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WELCOME

THE HUBBLE SPACE Telescope was nearly the biggest disaster in science. But 25 years after its launch, it is known for its succession of extraordinary photos, each more stunning than the last. But what have they taught us? Amy Tyndall polled 100 astronomers to find out, and we present the answers on p35.

This month is the 200th anniversary of the biggest volcanic eruption in recorded history. Tambora caused gloom in Europe for months, with the result that a group of writers on holiday in Switzerland decided to stay inside and tell each other stories. One of them was Mary Shelley, and I'm sure you know the rest. Bill McGuire explores the eruption on p60.

While the fictional Frankenstein reanimated body parts, scientists today are attempting to replicate life in a computer. It might seem obscure, but the project might one day save your life. Find out more on p47.

If you're a Trekkie, you'll know all about the tricorder. But it's just a sci-fi gadget, right? Wrong! Several companies are set to make handheld medical scanners an everyday reality, as we report on p54.

Finally, if you're an aspiring science writer you'll want to know about an exciting new competition with some great prizes – turn to p23 for the details.

Graham

Graham Southorn, Editor

PS Don't miss our June issue, on sale 30 April 2015

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THIS MONTH WE...

...travelled to Belgium to test drive the Toyota i-Road. This cool vehicle combines the benefits of a car and a motorbike and is a bit too much fun, in our opinion. Check it out in next month's issue.

...chatted to author Nessa Carey about why the junk DNA in our bodies is ready for a rebrand. Listen to Nessa on the *BBC Focus* podcast at sciencefocus.com/podcast

...boogied around the *BBC Focus* office listening to music on some of the latest high-res audio devices. Turn to p82 to find out which one was our favourite.

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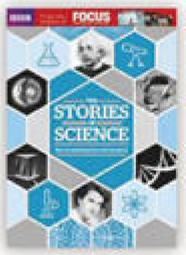

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APPEARING IN THIS ISSUE...

Lilian Anekwe

Lilian is a health journalist and the editor of *Pharmafocus*. On p54, she finds out more about the medical tricorders currently in development. Trekkies rejoice!

Bill McGuire

Volcanologist BIll is an emeritus professor at University College London. On p60, he writes about the Tambora volcano and tells us when a similar eruption could occur.

Katherine Nightingale

Katherine is a science writer at the Medical Research Council and has an MSc in molecular biology. She explains how scientists are replicating life in computers on p47.

Amy Tyndall

Amy has a doctorate in astrophysics and works for the European Southern Observatory. On p35 she reveals the 10 most important discoveries made by Hubble.

WANT TO SUBSCRIBE? Turn to p30 to get five issues of *BBC Focus* for just £5

SUBSCRIBER BONUS Turn to p30 to find out more about astrophysics from astronomer **Prof Ian Morison**

COVER: ANDY POTTS

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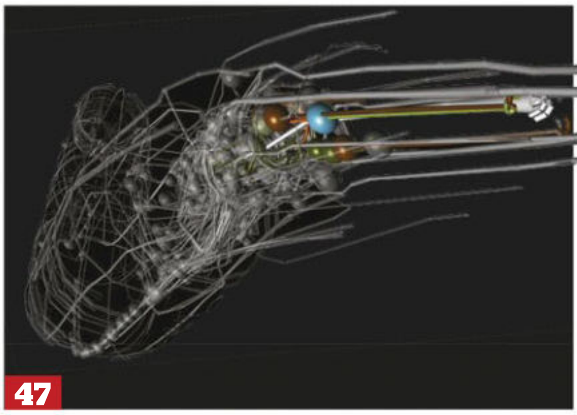
Scientists have some clever ways of figuring out the ages of historical finds, whether they're looking at fossils or ancient ceramics



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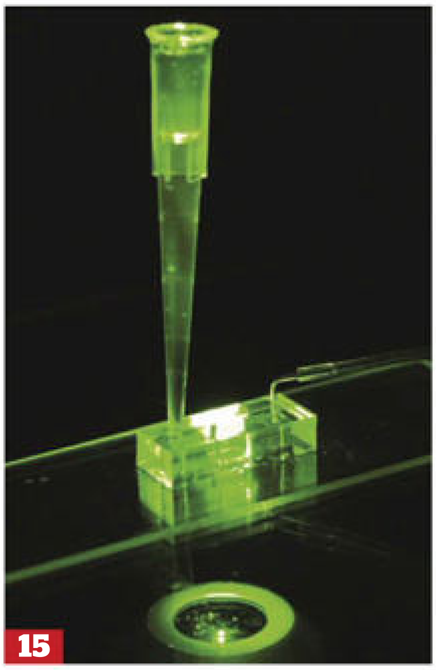
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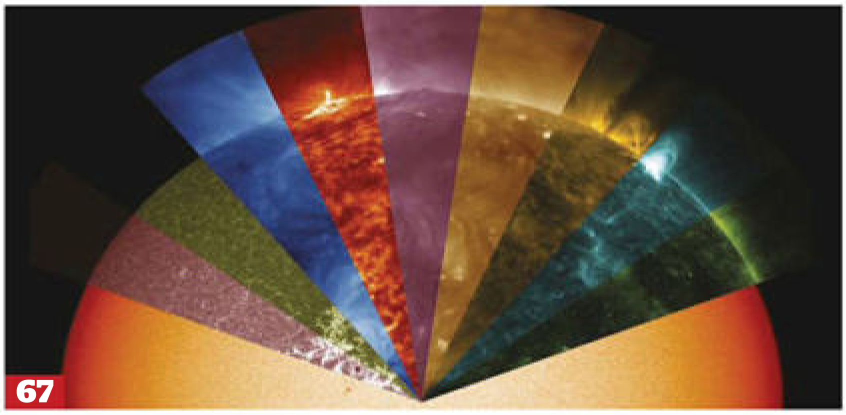
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Awe-inspiring images from the world of science

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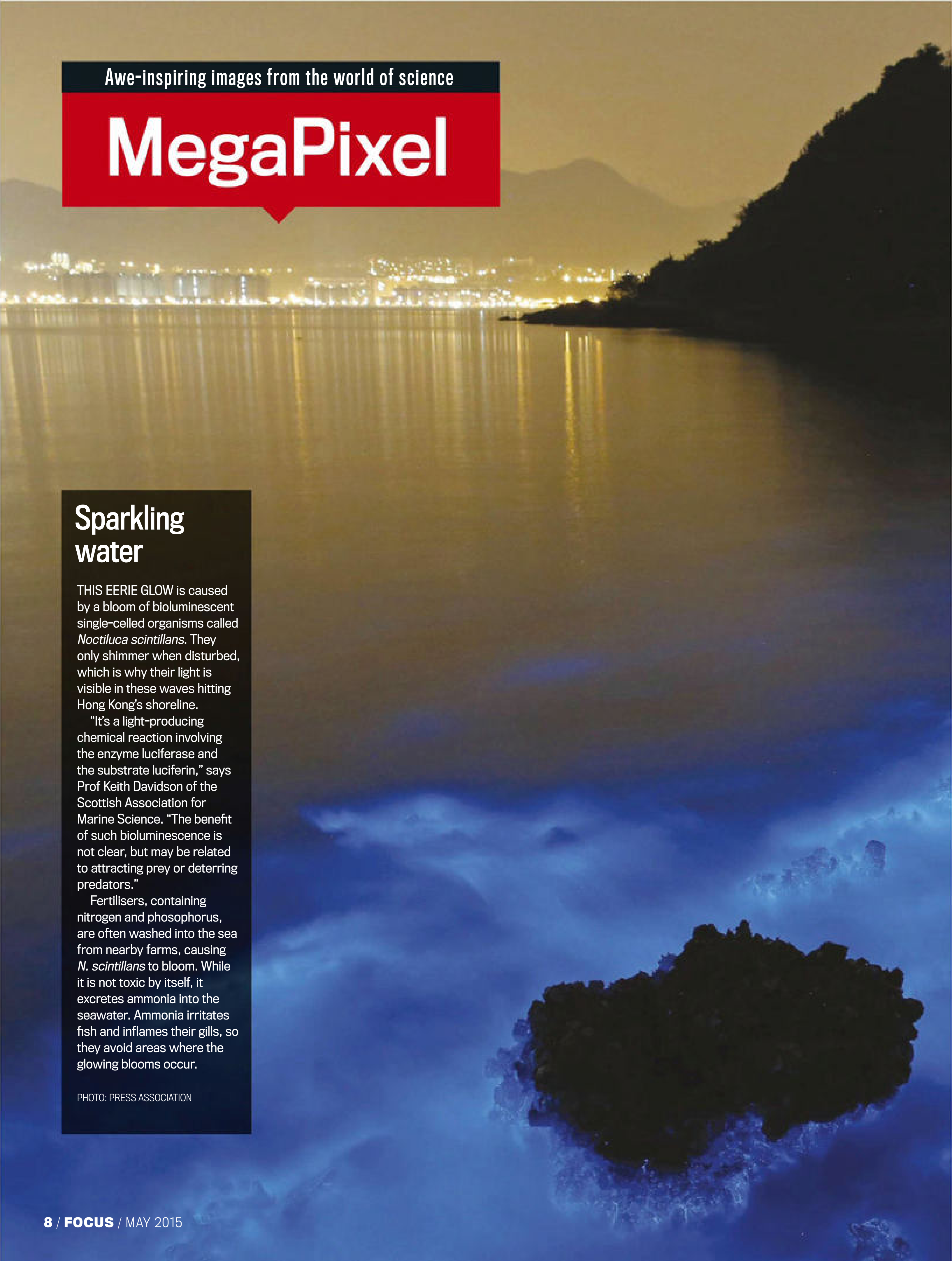


Sparkling water

THIS EERIE GLOW is caused by a bloom of bioluminescent single-celled organisms called *Noctiluca scintillans*. They only shimmer when disturbed, which is why their light is visible in these waves hitting Hong Kong's shoreline.

"It's a light-producing chemical reaction involving the enzyme luciferase and the substrate luciferin," says Prof Keith Davidson of the Scottish Association for Marine Science. "The benefit of such bioluminescence is not clear, but may be related to attracting prey or deterring predators."

Fertilisers, containing nitrogen and phosophorus, are often washed into the sea from nearby farms, causing *N. scintillans* to bloom. While it is not toxic by itself, it excretes ammonia into the seawater. Ammonia irritates fish and inflames their gills, so they avoid areas where the glowing blooms occur.

PHOTO: PRESS ASSOCIATION

MegaPixel

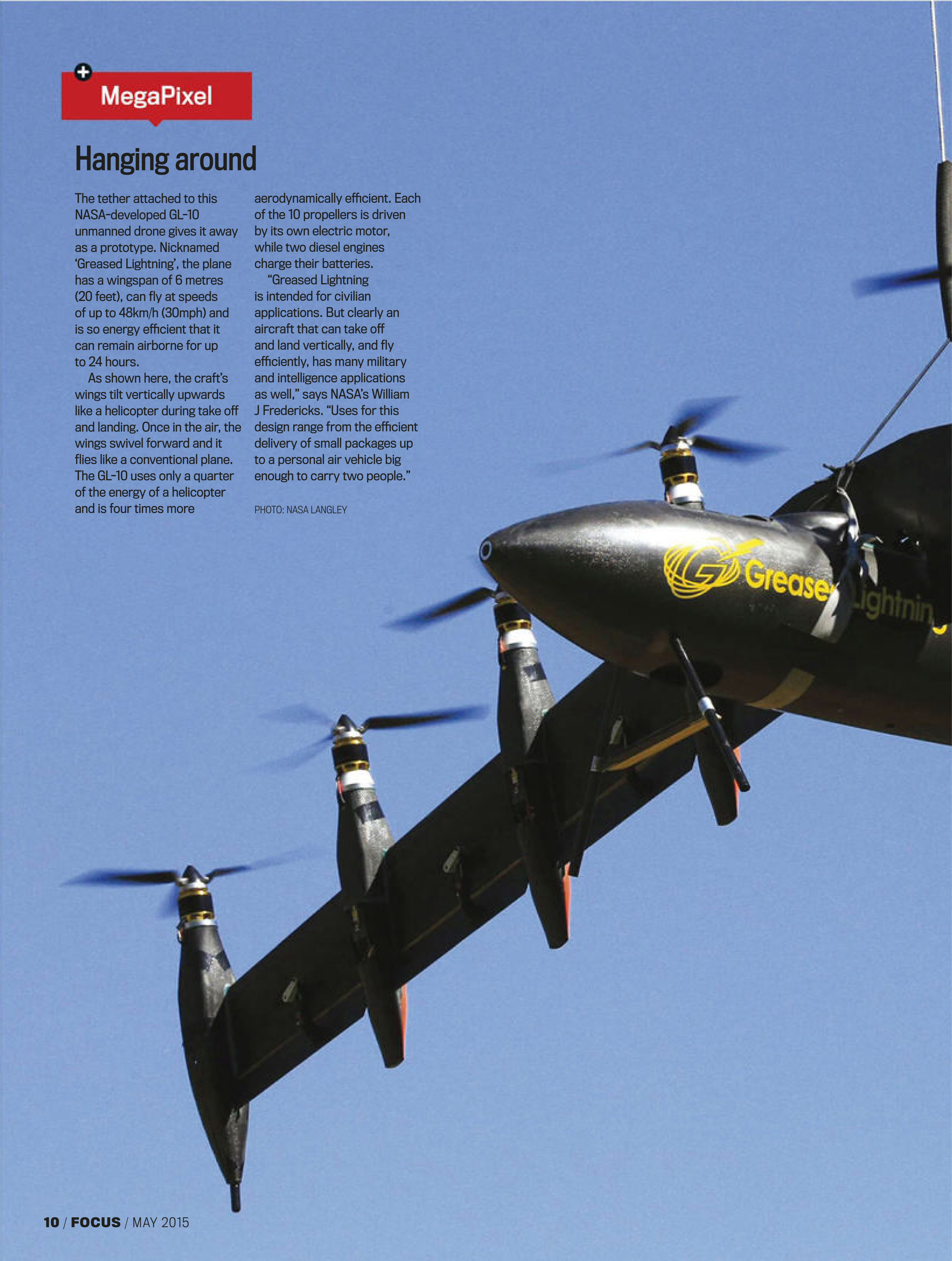
Hanging around

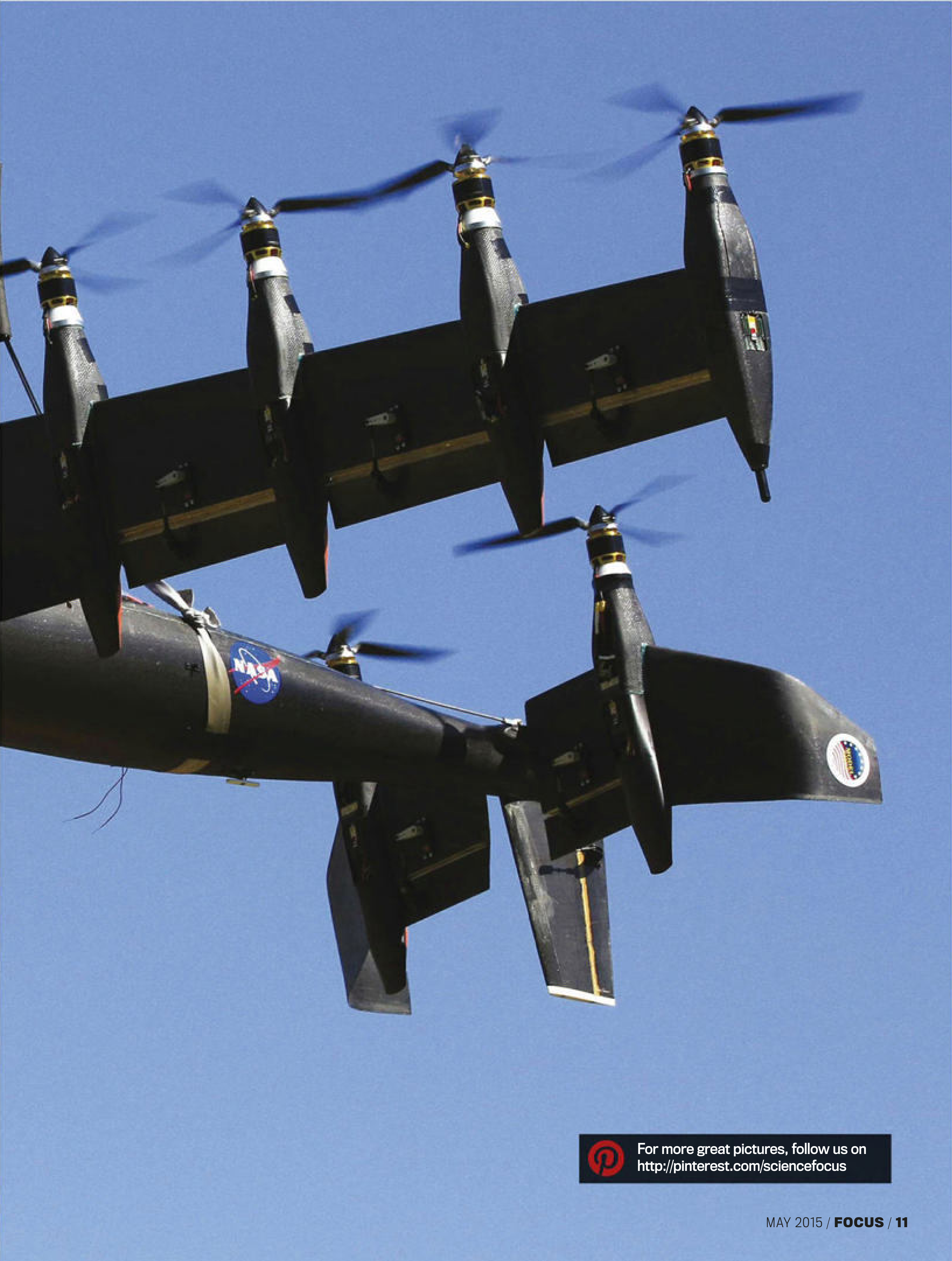
The tether attached to this NASA-developed GL-10 unmanned drone gives it away as a prototype. Nicknamed 'Greased Lightning', the plane has a wingspan of 6 metres (20 feet), can fly at speeds of up to 48km/h (30mph) and is so energy efficient that it can remain airborne for up to 24 hours.

As shown here, the craft's wings tilt vertically upwards like a helicopter during take off and landing. Once in the air, the wings swivel forward and it flies like a conventional plane. The GL-10 uses only a quarter of the energy of a helicopter and is four times more aerodynamically efficient. Each of the 10 propellers is driven by its own electric motor, while two diesel engines charge their batteries.

"Greased Lightning is intended for civilian applications. But clearly an aircraft that can take off and land vertically, and fly efficiently, has many military and intelligence applications as well," says NASA's William J Fredericks. "Uses for this design range from the efficient delivery of small packages up to a personal air vehicle big enough to carry two people."

PHOTO: NASA LANGLEY





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MESSAGE OF THE MONTH

Musical statues isn't the wisest game to play while driving

Passengers in peril

'Britain's most dangerous roads' by Tobias Jolly was thought provoking. The statistic that each seven miles ridden on a motorbike racks up one micromort is quite frightening and easily believable, given the exposed and solo nature of the rider. [One micromort is a one-in-a-million chance of death]. However, travelling by car or by train is not such a solo adventure. A major negative for road safety might be other people in the car – the arguing spouse, the noisy kids. I just wanted to check that the number of travellers has been accounted for. I want to know how many miles the train itself will travel before I am at serious risk, not how many miles all the passengers combined have travelled in that train.
Steve Card

Tobias Jolly replies: *The train figure is based on passenger miles, and takes into account the combined probability of the train crashing and a given individual dying. (The probability that your train will crash at all is significantly higher than one in a million for every 6,000 miles.) The car figure is based on vehicle miles. So 300 miles per micromort is the total expected risk for the occupants of your average car. The total risk will increase with the number of passengers and, as you mention, there may also be the added effect of driver distraction. This might produce a curve, with the total risk exposure rising rapidly as you add more people to a car. It's interesting to consider the huge range of different factors that can influence risk.*

Write in and win!

The writer of next issue's Message of the Month wins an 8GB Eyefi Mobi Wi-Fi SD card, worth £33.99. It transfers photos wirelessly from your digital camera to your smartphone, tablet, PC or Mac. The card also comes with 90 days' free membership to the Eyefi Cloud service. **eyefi.com**

Drive safe

Having read Tobias Jolly's article about dangerous roads (March, p64), I will now change my route planning technique. I shall wait until everyone else who has read the article heads for the safest routes, and I'll then head for what were more dangerous highways. These will now be safer, as there are fewer vehicles on them. Please could one of your esteemed contributors calculate approximately how long it will be before the maximum number of drivers make the initial switch?
Kevin Wright, Harlow

Are plants conscious?

The comment on plant consciousness (March, p74) was misleading. [American biologist] Lynn Margulis described consciousness "in its simplest form as awareness of the outside world". Only humans possess the attributes of human consciousness. But all other organisms are conscious in their own way and with the capabilities that evolution has provided them, since all sense the outside world – including plants. It is both biased and subjective to believe that because other organisms don't have our consciousness attributes, they lack consciousness altogether. Even nerve cells are not needed. Margulis referred to the conscious cell, and plants have millions of them. Plants are not reflex organisms – a common misconception resulting from controlled experimental circumstances, and the way plant behaviour is taught.
Prof Anthony Trewavas, University of Edinburgh

PHOTO: ISTOCK X2, ANDREW LYONS, NASA

Living on Mars: bad idea!

I read with interest the feature 'One way to Mars' in the February issue (p38). I don't know why the idea of landing humans on Mars is being contemplated at all. This is a gross indulgence and totally unjustified. There are some aspects of space exploration that will remain comic book fantasies. Unlike many in the science community, I stopped reading those years ago. A journey into space is a journey into nowhere, into the abyss. Our place is here on Earth.
Vince Leonard, Bedford

I read with interest the article about the Mars project and the one thing your contributors did not mention, or seem to have considered, is the appalling cold of a Martian night. This will be a new experience for astronauts because up until now they have landed on the Moon – in daylight. On Mars, within 13 hours of landing, they will have 13 hours of intense cold! To venture outside at night will be folly. This is because Mars has no significant atmosphere to insulate the cold of the night. No wonder space travel is so expensive.
Peter Harman

It will certainly be chilly. According to NASA, at Mars's mid-latitudes the average temperature at night is -60˚C. But on the dark side of the International Space Station, it would be -250˚C were it not for the thermal control system that keeps astronauts comfortable. ***– Ed***

Get your woolly hats on! Mars temperatures plummet to -60˚C at night

Val McClean wonders whether jetlag is a new phenomenon

What causes jetlag?

Is there anyone knowledgeable enough to tell me when 'jetlag' was invented? In the late 1960s and 1970s, I was an air hostess (as we were called then) with British United Airways, a schedule airline flying all over the world. I was working long haul for some years: Brazil, Chile, Nairobi, Afghanistan and more. We didn't get much time off between flights, but we didn't suffer from 'jetlag' either! Tell me, were we a much stronger breed of human then? Seriously, though, I really would like to know more about this.
Val McClean

It's well documented that jetlag is due to the body's 24-hour circadian rhythms getting out of sync with the natural cycles of light and dark. A 2005 study entitled 'How to trick Mother Nature into letting you fly around or stay up all night', published in the Journal of Biological Rhythms*, detailed a 'preflight plan' to prevent it by shifting your rhythms. Perhaps you were following a similar plan without realising it!* ***– Ed***

I love 'Everyday science'!

What a marvellous page Helen Czerski writes each issue. I've followed it for several months and always have fun reading it. It's always well-written and on a great topic. I look forward to each new edition to see what you will write about next. I love the quirky illustrations that go with it – illustrator Andrew Lyons is a very good choice with a great style. Never change that winning team!
Daniela Faber, Hamburg, Germany

Oops!

- In the April issue on p79, we said that the nano power generator creates "90V of energy and 0.8 milliwatts of current". This should have been 90V of potential difference and 0.8 milliwatts of power. Apologies for the error.

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DISCOVERIES

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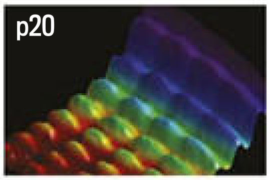
p18

COULD TITAN HOST LIFE?

Saturn's largest moon could theoretically support life in its methane seas



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LANDMARK LIGHT IMAGE

Light has been pictured behaving as both a wave and a particle

p23

BAD LUCK, MUM

New research suggests kids are more like their fathers

THE BIG STORY

'HEART-ON-A-CHIP'

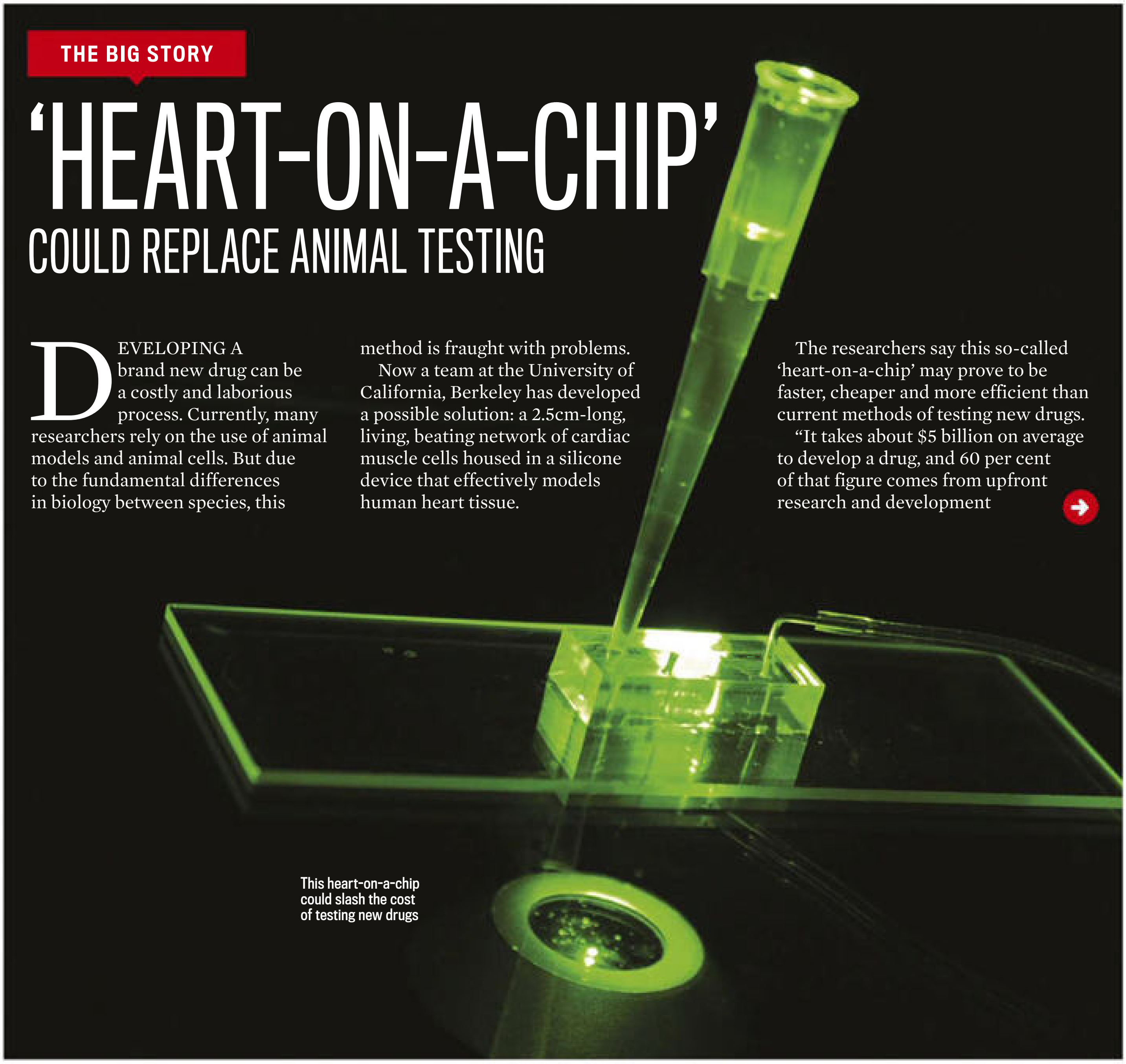
COULD REPLACE ANIMAL TESTING

DEVELOPING A brand new drug can be a costly and laborious process. Currently, many researchers rely on the use of animal models and animal cells. But due to the fundamental differences in biology between species, this method is fraught with problems.

Now a team at the University of California, Berkeley has developed a possible solution: a 2.5cm-long, living, beating network of cardiac muscle cells housed in a silicone device that effectively models human heart tissue.

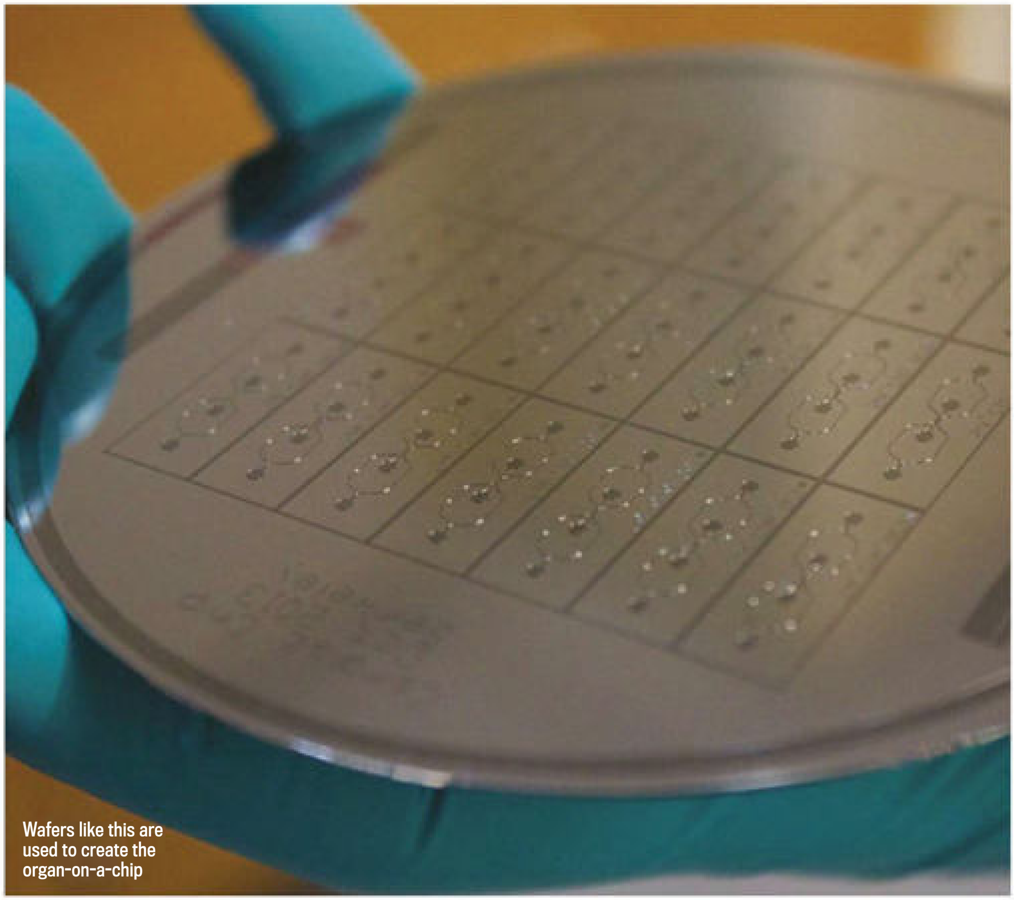
The researchers say this so-called 'heart-on-a-chip' may prove to be faster, cheaper and more efficient than current methods of testing new drugs.

"It takes about $5 billion on average to develop a drug, and 60 per cent of that figure comes from upfront research and development



This heart-on-a-chip could slash the cost of testing new drugs

PHOTO: UC BERKELEY



Wafers like this are used to create the organ-on-a-chip

costs," says researcher Kevin Healy. "Using a model of a human organ could significantly cut the cost and time of bringing a new drug to market. Ultimately, these chips could also replace the use of animals to screen drugs for safety and efficacy."

The heart cells were made using human-induced pluripotent stem cells – cells that can be manipulated to grow into different types of tissue. These were loaded into a 3D model made from silicone and designed to imitate the structure of tissue fibres in the human heart. Tiny channels on either side of the cell act as blood vessels, mimicking the exchange of nutrients and drugs with human tissue.

Within 24 hours of being loaded into the chamber, the heart cells began beating on their own at a normal rate of 55 to 80 beats per minute.

The team then tested the system using four well-known cardiovascular drugs – isoproterenol, E-4031, verapamil and metoprolol – and found that the effects on the heart tissue's beat rate were consistent with those seen in normal human adults. The heart-on-a-chip remained functional over several weeks, meaning that it could be used to test different drugs over its lifetime.

"This system is not a simple cell culture," says lead author Anurag Mathur. "We designed it so that it is dynamic; it replicates how tissue in our bodies actually gets exposed to nutrients and drugs."

In the future, the system could be adapted to model human genetic diseases or even multiple organs, the researchers say.

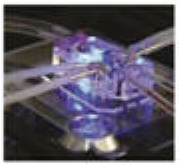
Watch the model heart beating on YouTube at http://bit.ly/1ClYMDy

TIMELINE

A history of 'organ-on-a-chip' research

1999
Cornell University's Michael Shuler coins the term 'animal-on-a-chip' to describe his system of growing cells inside a chambered structure.

2011
Dongeun Huh from Wyss Institute for Biologically Inspired Engineering creates a lung-on-a-chip (pictured, right) using a polymer membrane lined with human lung cells.



2013
A team at the Wake Forest Institute for Regenerative Medicine in North Carolina manages to 3D bioprint a heart, a liver, a lung and blood vessels.

2015
Mark Donowitz at Johns Hopkins University begins work on a gut-on-a-chip by growing intestine cells with the aim of creating a functioning organ.

PHOTO: ANURAG MATHUR/HEALY LAB, WYSS INSTITUTE, ISTOCK X2

GOOD MONTH/ BAD MONTH

It's been good for:

THOSE WITH A SENSE OF PURPOSE

DO YOU SPRING out of bed in the morning, excited about all the possibilities the day will bring? If so, lucky you – a study at Mount Sinai Medical Center has found that those with a strong sense of direction and a feeling that life is worth living are 23 per cent less likely to die from all causes than listless counterparts.

MODERATE DRINKERS

IF YOU ARE on the hunt for a new partner, drinking a moderate amount of alcohol may help. Imbibing one 250ml glass of wine made the drinker appear more attractive, according to a University of Bristol study. It is thought the effect is due to small changes in appearance such as facial flushing.

It's been bad for:

HIPSTERS

ANYONE UNDER the impression that their topknot, sailor tattoos and ironic facial hair are an outward expression of their individuality might want to think again. Mathematician Paul Smaldino has created a model that shows that even if we try to be different, human behaviour always tends towards 'collective conformity'. It's why hipsters inevitably all end up looking the same, he says.

THE SHORT-TEMPERED

IF YOU HAVE a short fuse, there's more reason than ever to consider new ways of calming down. The risk of a heart attack can be up to eight times higher in the two hours following an intense burst of anger, a study at the University of Sydney has found.

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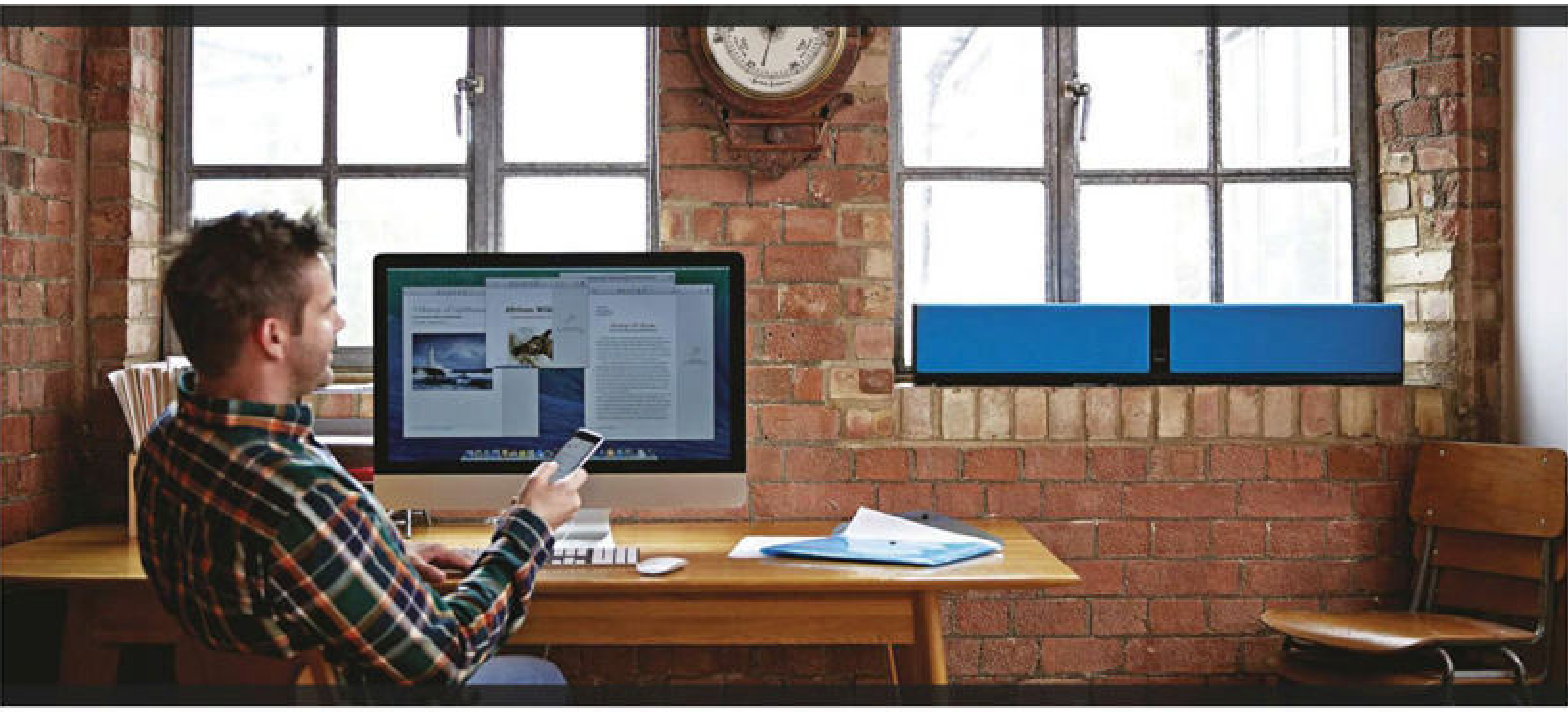
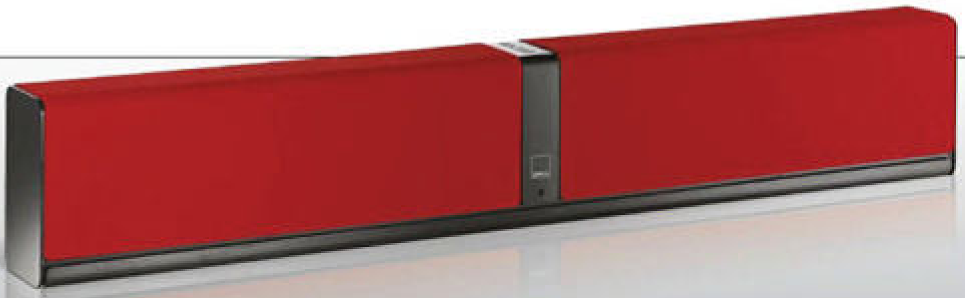


DALI KUBIK is a series of wireless speakers that combine DALI's legendary loudspeaker heritage with state-of-the-art digital amplification.
The new DALI KUBIK ONE and KUBIK FREE allow you to listen wirelessly to your music and movies at an incredible level of sonic detail.
These extraordinary sound systems give you the freedom to listen from any device, anywhere in your home - phones, tablets and laptops all swiftly and effortlessly connect.



Learn more about the KUBIKs at www.dalikubik.com

Technical specifications: Bluetooth APT-X wireless connectivity, Class D amplifier, wide range of inputs (3.5mm mini jack, RCA, Optical, USB), interchangeable colour grilles.

SPACE

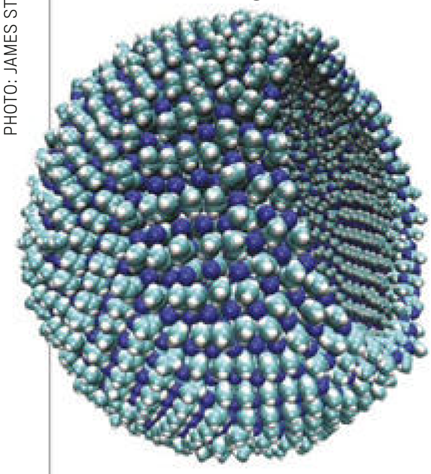
Life without water on Saturn's moon?

Saturn's moon Titan could theoretically be home to forms of life that don't rely on water

AS WATER PLAYED a key role in the development of all life on Earth, the search for life on other planets has largely looked for the presence of liquid H_2O. But perhaps life can arise in other environments.

This was the starting point for chemical engineers from Cornell University, who designed the azotosome: a hypothetical cell membrane that could survive in the harsh, cold, methane-rich world of Titan, Saturn's largest moon.

Cell membranes are found in every living thing and protect the inside of cells from the outside world. They do this by allowing certain substances through and blocking others. It is a process essential for life. Without it, the necessary chemical reactions would be unable to take place.


The azotosome could survive without H_2O

On Earth, cell membranes are made from a permeable substance known as the phospholipid bilayer and they exist in environments that contain water. In order to look for a potential methane-based equivalent, the team looked for compounds made from carbon, nitrogen and hydrogen. These elements are known to exist in the methane seas on Titan and are capable of self-assembling into membrane-like structures.

They found a match in acrylonitrile, which is present in Titan's atmosphere. It is a colourless, poisonous, organic compound used to make acrylic fibres and plastics on Earth.

"We're not biologists and we're not astronomers, but we had the right tools," says study leader Paulette Clancy. "Perhaps it helped, because we didn't come in with any preconceptions about what should be in a membrane and what shouldn't. We just worked with the compounds that we knew were there."

The next step is to investigate how these membranes could harvest energy and reproduce in the methane environment.

PHOTO: JAMES STEVENSON/CORNELL UNIVERSITY PHOTOGRAPHY X2

CLICK HERE

New websites, blogs and podcasts

SPACEPROB.ES

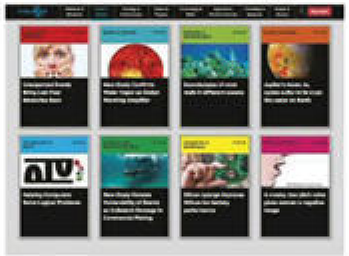
http://spaceprob.es

There are currently 29 space probes out in the cosmos, and they're all listed on this website – including everyone's favourite Mars rover, Curiosity. You'll find summaries of what the probes are currently doing, along with some well-curated links if you want to find out even more.

OCEARCH

ocearch.org

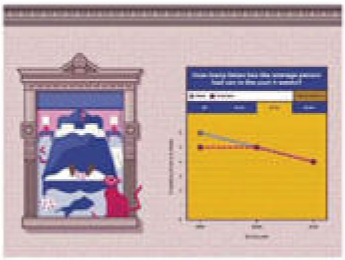
If sharks fascinate you, then why not track them all over the world? OCEARCH is a non-profit organisation that tags and tracks sharks. It then gives scientists access to all of the collected data, but you can take a look too. Read about how sharks are tagged and see how they move across the world's oceans.



PUBLISCIZE

publiscize.com

Now you can get your science news straight from scientists. Pretty much every topic is included on this site, including medicine, space, Earth science and materials. There are summaries of newly-published scientific papers written by the teams behind the research, along with links to the papers themselves.



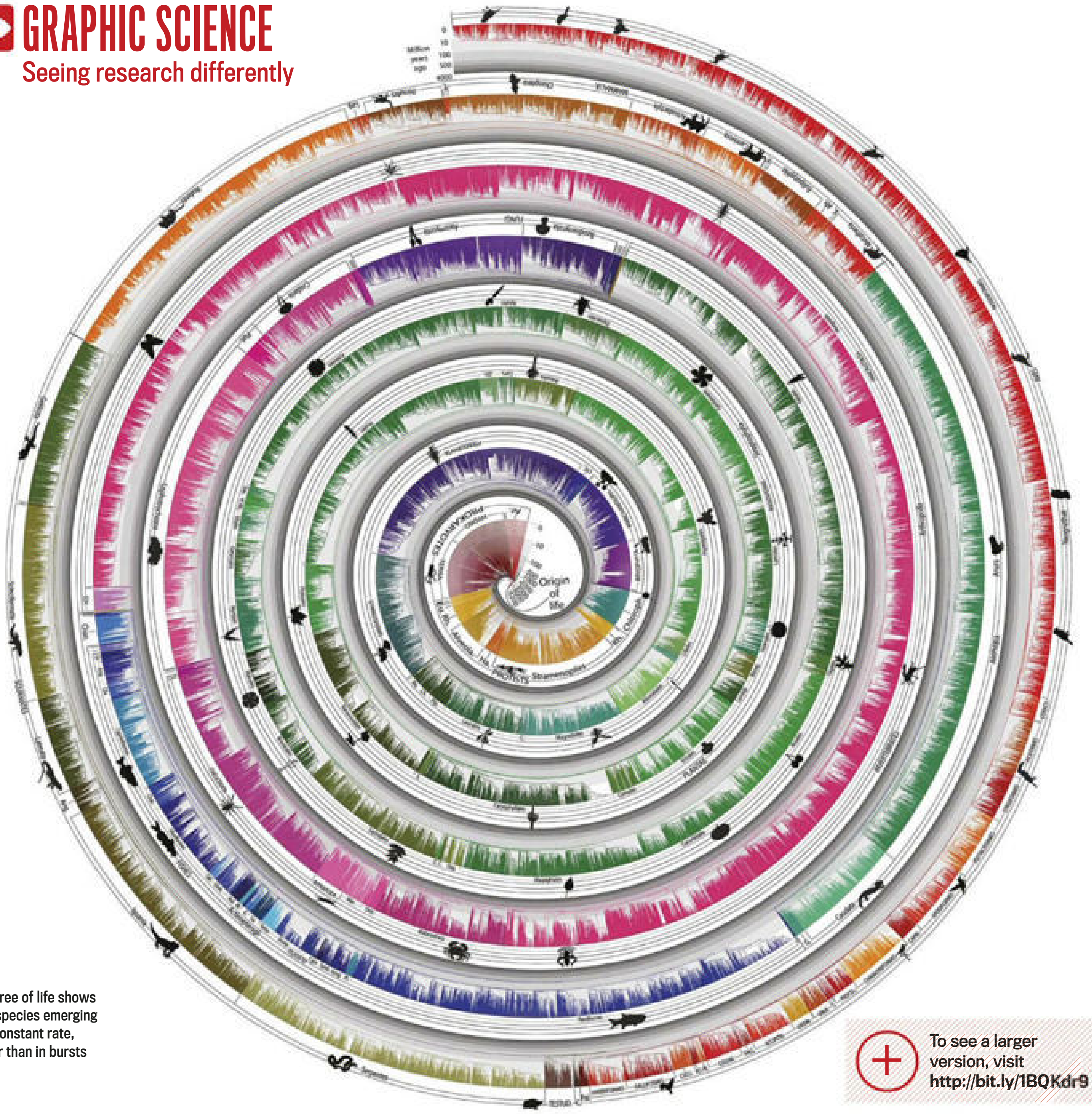
SEX BY NUMBERS

sexbynumbers. wellcomecollection.org

British people are not exactly the most forthcoming when it comes to sharing what we get up to in the bedroom. Which is why this funky website, launched as part of the Wellcome Collection's Sexology Season, is so fascinating. It offers a glimpse into the average person's sex life, based on some hard research data.

KELLY OAKES is Science Editor at BuzzFeed. She tweets from @kahoakes

GRAPHIC SCIENCE
Seeing research differently



This tree of life shows new species emerging at a constant rate, rather than in bursts

To see a larger version, visit http://bit.ly/1BQKdr9

EVOLUTION

'Tree of life' reveals species emerge every two million years

THIS KALEIDOSCOPIC SPIRAL shows the most accurate picture of the evolution of life on Earth. It was put together by researchers at Temple University in Philadelphia and details the emergence of more than 50,000 species, dating back to the origin of life itself.

The team pooled data from 2,274 studies investigating the molecular biology and genetic evolution of various species and fed it into custom-designed computer algorithms to create this detailed picture of the tree of life. Contrary to the conventional view that species diversification is driven by adaptation, the researchers say the new tree highlights the importance of random genetic events.

As ecological niches fill with species, competition for resources intensifies. The rise of new species might, therefore, be predicted to slow down. But the study shows a new species emerging roughly once every two million years.

"The constant rate of diversification that we have found indicates that the ecological niches of life are not being filled up and saturated," says researcher S Blair Hedges. "This is contrary to the popular alternative model which predicts a slowing down of diversification as niches fill up with species. This finding shows that speciation [process by which new species arise] is more clock-like than people have thought."

The team plans to add more data and wants to develop new tools to allow other researchers to update the ever-growing tree.

ILLUSTRATOR: DR S BLAIR HEDGES

1 MINUTE EXPERT

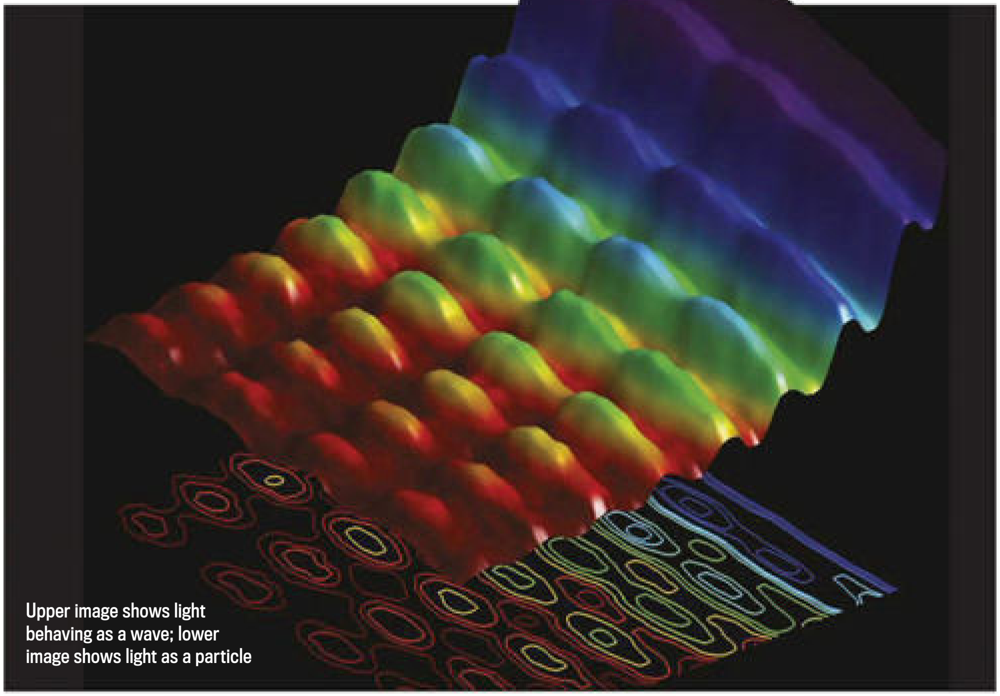
MOTS-c

Is that a new type of safety test for scooters?
Way off. It's a newly discovered hormone that appears to counteract some of the negative health effects caused by eating a diet that's high in fat.

Tell me more.
Hormones act as the body's signals, triggering various physiological responses. Most hormones are encoded in the DNA of the cell's nucleus, but MOTS-c is unique in that it is encoded in the DNA of mitochondria instead. Mitochondria are the powerhouses of cells that convert food into energy.

So what exactly does it do?
When the team injected MOTS-c into mice that were fed on a diet high in fat, they didn't become obese or develop insulin resistance in the same way their natural siblings did. The mechanisms involved in the effect are present in all mammals, including humans, the researchers say.

Fantastic - make mine a double cheeseburger!
Hold your horses. Human trials aren't scheduled for another three years. So stick to your healthy diet in the meantime.



Upper image shows light behaving as a wave; lower image shows light as a particle

PHYSICS

Landmark picture of light

IT IS ONE of the most famous examples of so-called 'quantum weirdness': light can act as both a particle *and* a wave simultaneously. Now, a research group at Switzerland's École Polytechnique Fédéral de Lausanne (EPFL) has captured the first ever snapshot of this beguiling dual behaviour by using an innovative electron-based imaging technique.

"This experiment demonstrates that, for the first time ever, we can film quantum mechanics, and its paradoxical nature, directly," says lead researcher Fabrizio Carbone.

To create the image, they fired a laser at a metallic nanowire, causing charged particles within it to vibrate. As a result, light waves moved up and down the wire in both directions and combined to form a 'standing wave' – a wave that looks like it's frozen in place. They then shot a beam of electrons at the nanowire.

When the electrons hit the photons (light particles) travelling up and down the wire, they either sped up or slowed down. Using an ultrafast microscope to record the position at which this change in speed occurred, the team was able to visualise the standing wave, revealing the wave nature of light. As the change in speed appears as an exchange of packets of energy known as 'quanta' between the electrons and the photons, light is simultaneously seen to behave like a particle.

"The ability to directly image quantum mechanical effects, and control them via light pulses, opens new possibilities," says Carbone. "For example, one may engineer circuits that function as we imaged in this work, and exploit their quantum properties to create advanced logic gates or similar exotic devices." Watch a video by EPFL here: http://bit.ly/1Exawox

WHO'S IN THE NEWS?

Sergio Canavero

Italian surgeon

Who's he and what has he done?
Sergio Canavero is based at the Turin Advanced Neuromodulation Group in Italy. Canavero has published a paper detailing a technique he says could be used to graft a living person's head onto the body of a donor. What's more, he says it could happen in as little as two years.

What?! How is he going to do that?
The technique involves cooling the head and body to increase the time that cells can live without oxygen. After cutting through the neck, the blood vessels and spinal cords will be joined together using special chemicals. The patient will then be put in an induced coma for a month while they heal.

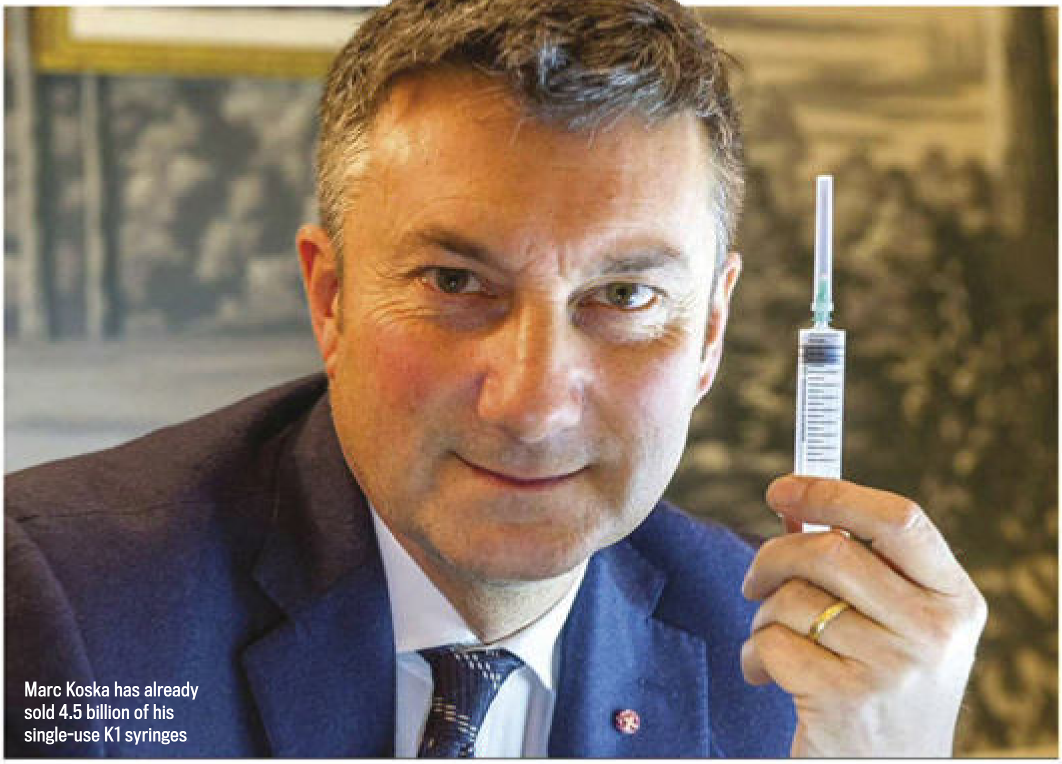
Right. Well, that sounds easy enough...
Not quite. A number of critics have hit out at Canavero, saying there is no evidence that simply connecting the spinal cord to the brain will allow the patient to successfully control the donor body. There are also, of course, some serious ethical questions that such an extreme procedure would raise.

PHOTO: FABRIZIO CARBONE/EPFL, JEREMY YOUNG/NI SYNDICATION, MASSIMO BREGA ILLUSTRATOR: DEM ILLUSTRATION

New syringes will make injections safer

DAVID SHUKMAN

The science that matters



Marc Koska has already sold 4.5 billion of his single-use K1 syringes

YOU HAVE A headache, but you do not reach for a tablet. Instead, you opt for something you are convinced is more effective: an injection.

That is the case in many of the poorest countries, where equipment such as a syringe attached to a needle is seen as more useful than some little pill from a packet. The promise of medical technology exerts a powerful lure.

Most of us in the UK would do almost anything to avoid injections. But around the world, some 16 billion jabs are administered every year, and often to people who obviously do not understand the risks.

I saw this for myself in Cambodia recently. The remote village of Roka, a quiet community of rice farmers, is in the grip of an outbreak of HIV. At the time of writing, more than 270 people were infected and five had died.

The common factor was that they had been given injections with reused syringes. An unlicensed medic had administered the jabs, passing the HIV from one to another, and he is now in custody facing murder charges.

So a simple piece of medical equipment, which must have saved countless lives since it started to be mass-produced in the last century, can be a killer in the wrong hands.

The problem is that even if the self-styled medic had tried to sterilise the equipment between each use, it's almost impossible to be sure of killing off every bug or virus. The safest solution is a syringe that can only be used once. And that is exactly what British inventor Marc Koska has designed.

His K1 syringe, which has earned him awards, has a feature that means it 'auto-disables' if someone tries to refill it. I had a go myself: as you draw back the handle of the plunger, there's a click as it snaps off.

Now that the costs of these 'smart' syringes broadly match those of normal ones, there is a real chance that they will catch on. The World Health Organization has told the manufacturers and big donors that it wants the syringes to become standard by 2020.

That may be optimistic. But next time I'm having an jab, I'll be paying a lot more attention.

DAVID SHUKMAN is the BBC's Science Editor. @davidshukmanbbc

THEY DID WHAT?!

Music composed for cats

What did they do?

David Teie, a composer at the University of Maryland, wrote a piece of music specifically for cats. It was based on rhythms that mimic the cadence of purring and the suckling rates of kittens, and sliding tones modelled after cat vocalisations.

What did they find?

The cats approached and rubbed themselves on the loudspeakers much more when they heard the feline compositions than when they were played Bach's *Air On The G String* and Fauré's *Élégie*, which are both pieces that humans find relaxing. They also responded more quickly after hearing the cat-based music.

Why did they do it?

The results suggest that music could be composed for other species, which could be used to calm animals being kept in zoos or shelters. Listen in at musicforcats.com

PATENTLY OBVIOUS with James Lloyd

Inventions and discoveries that will change the world

Say cheerio to BO

WHEN YOU'RE GOING on a date or an all-important business trip, the last thing you want is a BO (body odour) problem. After all, no one wants to sit next to someone who smells like a skunk's squash kit. Thankfully, Google is on the case. Its 'odour-removing device' monitors your body temperature, heart rate, sweat levels and other statistics so that it knows when you're working out or feeling stressed. If it thinks you're likely to pong, the device sprays out a perfume to counteract your funky fragrance.

The device would be able to store information such as your sweat history, exercise schedule and appointment calendar so that it knows when you're likely to need perfuming again. It might even use social networks to track the location of your contacts, suggesting an alternative route so that you can avoid subjecting them to your unpleasant whiff.

Patent number: US 8,950,238

Invisible ink

AS MANY AS one in three people regret their tattoos, so removing unwanted body art is big business. Usually, lasers break down the ink in a painful and expensive process. But a PhD student at Dalhousie University has developed a cheap, painless alternative. Alec Falkenham's tattoo removal cream targets the cells, or 'macrophages', that swallow the pigment when the tattoo is originally formed. Agents in the cream encourage new macrophages to gobble up the old, ink-filled ones, resulting in a tattoo that gradually fades away.

Patent pending

Inner-city crops

ARE YOU A city dweller who wants to grow fruit and veg? Well here's one for you. My Terrace Farmer is a solar-powered greenhouse that's small enough to fit in a tiny backyard or a balcony. Developed by Colorado's Solar Greens Company, the greenhouse is portable, can be assembled in an afternoon, collects rainwater and creates its own compost. Best of all, the Garden Genie add-on automatically waters and lights your plants when it's needed, monitoring temperature and soil humidity so that you don't have to.

Patent pending

PHOTO: NASA, ISTOCK X2 ILLUSTRATOR: DEM ILLUSTRATION

SPACE

Mars was home

BEFORE IT BECAME the barren Red Planet, a vast ocean covered 20 per cent of the surface of Mars, NASA scientists have found. The discovery means it may have remained habitable for longer than previously thought.

About four billion years ago, the young planet held around 20 billion cubic km of water, which is enough to cover its entire surface to a depth of 140m. However, it is likely that the liquid pooled to form a vast ocean covering almost half of the northern hemisphere, the researchers say.

The findings come from an international collaboration involving the Very Large Telescope, the Keck II telescope and the NASA Infrared Telescope Facility. They are based on measurements of the amount of HDO – a heavier form of water found on Mars.

"I am again overwhelmed by how much power there is in remote sensing on other planets using astronomical telescopes," says researcher Ulli Kaeufl. "We found an ancient ocean more than 100 million kilometres away."

Due to its heavier weight, less HDO is lost to space than regular water. This means that the greater the water loss from a planet, the greater the ratio of HDO to regular H_2O in the water that remains.

By comparing the ratio of HDO to H_2O in water on Mars today and comparing it to water trapped in a 4.5 billion-year-old Martian meteorite, the team could estimate how much water has escaped into space.

"With Mars losing that much water, the planet was very likely wet for a longer period of time than previously thought, suggesting it might have been habitable for longer," explains researcher Dr Michael Mumma.

There was plenty of water on Mars four billion years ago, when it could have supported life

GENETICS

Mammals are more like their fathers

THE PHRASE 'LIKE father, like son' may have to be updated to include daughters. According to a study on lab mice at the University of North Carolina, mammals are more like their dads than their mums.

Although we inherit equal amounts of genetic mutations from each parent, the study says that mammals use more DNA from the dad. Mutations handed down from parents show up in many common but complex diseases that involve multiple genes, such as heart disease, schizophrenia and cancer, so studying them may shed light on mechanisms involved.

To find the effect, the team selected three genetically diverse strains of mice and bred them to create nine different types of offspring in which each strain was used as both father and mother. When the mice reached adulthood, the team measured gene expression in four different types of tissue, including in the brain. The researchers then calculated how much gene expression was derived from the mum and the dad for

to a giant ocean

COMPETITION

Calling all wannabe science writers

Put your science writing under scrutiny with our competition

HAVE YOU ALWAYS fancied having a bash at science journalism but weren't sure how to get started? Well, now's your chance. The University of the West of England's Science Communication Unit is launching a writing competition in conjunction with *BBC Focus*.

The competition is open to anyone who doesn't write for a living, and entries from bloggers and scientists are welcome. The theme this year is 'the science that will transform our future'. To enter, simply write an article on that theme in a style that's suitable for publication in *BBC Focus*.

The judges, who include *BBC Focus* editor Graham Southorn and UWE's Andy Ridgway and Dr Emma Weitkamp, will be looking for lively, well-researched stories on thought-provoking topics. Articles must be no longer than 700 words and previously unpublished. Only one entry per person will be accepted.

Entrants will be split into two age categories: 20 and under, and 21 and over. The winning articles will be published in *BBC Focus* magazine, and on the UWE and *BBC Focus* websites, and the winners will also receive a year's subscription to *BBC Focus*. And if you're over 18 you'll have the chance to spend a week's work experience with the *BBC Focus* team in Bristol, as well as take a taster science writing course at UWE.

You'll need to get your entries in by 5pm on 19 June 2015, so get your thinking caps on! For full terms and conditions and details of how to enter the competition, visit: www.uwe.ac.uk/sciencewriting2015

every gene in the genome. Gene expression is crucial for human health and links DNA to proteins, allowing them to carry out various functions inside cells.

"This expression level is dependent on the mother or the father," says senior author Pardo-Manuel de Villena. "We now know that mammals express more genetic variance from the father. Imagine that a certain kind of mutation is bad. If inherited from the mother, the gene wouldn't be expressed as much as it would be if it were inherited from the father. So the same bad mutation would have different consequences in diseases that were inherited from the mother or from the father."

"Aw, she looks just like her dad!"

10 DISCOVERIES THAT WILL SHAPE THE FUTURE

10 Tooth decay treatment

Beavers have iron-rich enamel, which gives their teeth an orangey colour

EVER WONDERED HOW beavers have such strong teeth despite not having access to toothpaste, mouthwash or a dentist? It turns out that iron built into the chemical structure of their gnashers gives them protection against decay. The discovery was made by researchers at Northwestern University and could lead to more effective treatments for human tooth decay, they say.

9 Pollution-busting flags

HERE'S A BREAKTHROUGH that is really flying the flag for green technology. Literally. Scientists at The University of Sheffield have coated advertising flags with a catalytic solution that removes harmful nitrogen oxide from the air. They hope the technology could soon be used to help reduce traffic emissions at petrol stations.

An earlier trial of the tech saw this poem printed on a pollution-zapping poster

8 Power from pee

A TOILET HAS been designed that can generate power from urine. The system, which has been produced by the University of the West of England and Oxfam, is based on a fuel cell that uses live microbes. These feed on urine and convert it into electricity. It is hoped the tech can be used to power lighting in refugee camps.

The toilet prototype is available to use at UWE

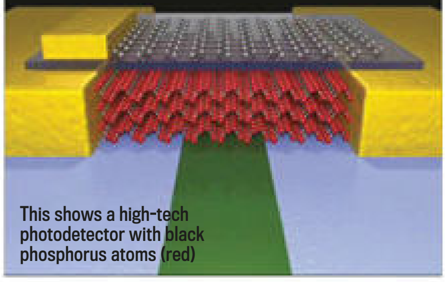
7 Leg muscle grown in laboratory

The researchers want to try creating lab-grown muscle for larger animals than mice

YOU MAY NO longer have to spend hours in the gym squatting to get thighs like Sir Chris Hoy. Scientists have grown a functioning leg muscle from engineered cells cultured in a dish and successfully grafted it onto a mouse. The method could allow for patient-specific treatments for a large number of muscle disorders, they say.

6 Wonder material to speed up internet

MOVE OVER GRAPHENE, there's a new wonder material on the block. Black phosphorus, a crystalline form of the stuff used in match heads, could be used in ultra-fast communications. A team at the University of Minnesota has built a system that sends optical data at speeds of three billion bits per second, equivalent to downloading an HD movie in 30 seconds.



This shows a high-tech photodetector with black phosphorus atoms (red)

PHOTO: MICHAEL GRAYDON TORONTO, UNIVERSITY OF SHEFFIELD, ISTOCK, YAO LU/UCL, L BRIAN STAUFFER, UNIVERSITY OF MINNESOTA, UNIVERSITY OF MICHIGAN MEDICAL SCHOOL, UWE

5

Batteries from packaging

WE'VE ALL BEEN there. You've just had a new TV delivered and are left wondering what to do with all the packing peanuts left in the box. Now, a Purdue University team has developed a way of converting them into carbon microsheets that can be used as anodes in rechargeable batteries. It's a cheap process and the resulting material performed better than existing ones.

4

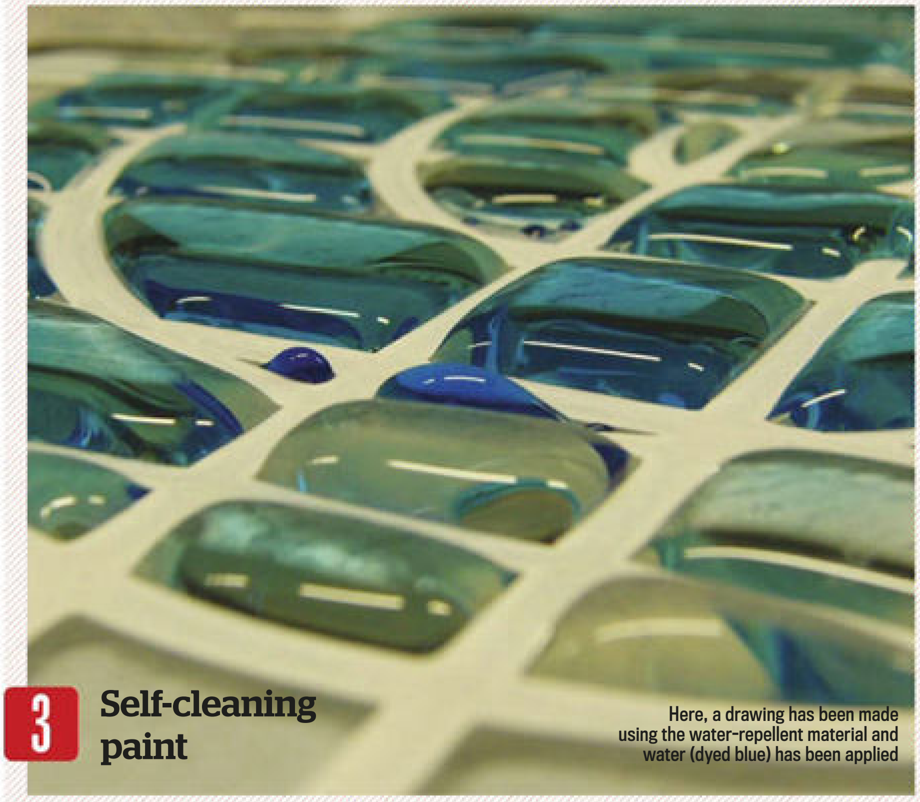
Solar-powered shrimp

THEY MAY TASTE great in a curry, but shrimps can also be turned into electricity generators. Researchers at Queen Mary University of London have created solar cells from chitin and chitosan, chemicals found in the shells of crustaceans. They could be used in wearable chargers for tablets and phones, or in semi-transparent films for windows, the researchers say.

This shrimp is safe - we don't eat this species

3

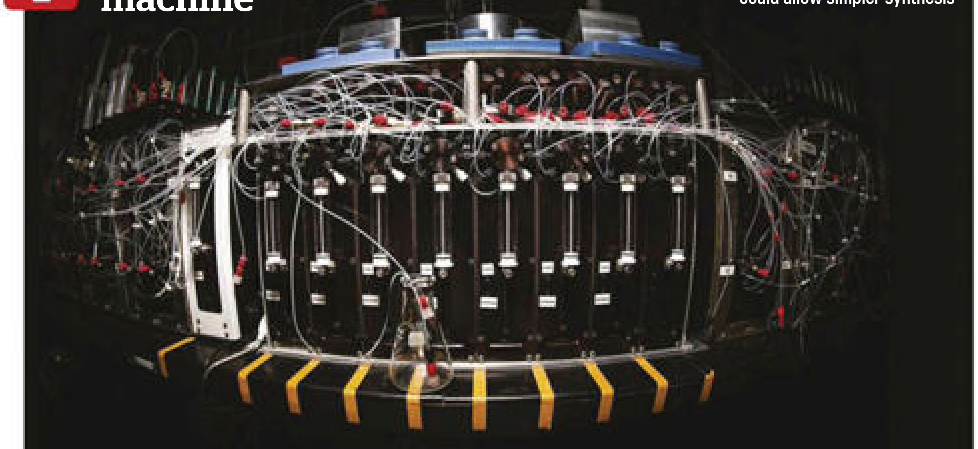
Self-cleaning paint


Here, a drawing has been made using the water-repellent material and water (dyed blue) has been applied

IT'S A WINDOW cleaner's worst nightmare: a sprayable coating that can make almost any surface clean itself. The substance was created using titanium dioxide nanoparticles by a team at UCL. The paint can be applied to clothes, paper, glass and steel and even maintains its self-cleaning properties after being scratched and scuffed. It works by being extremely water-repellent.

2

Molecule making machine


Many chemicals are tricky to make in the lab, but this machine could allow simpler synthesis

IT'S LIKE A 3D printer for molecules. Chemists at the University of Illinois have designed a machine to assemble complex molecules with the click of a mouse. The process could greatly speed up drug development, they say. The technique works by breaking down complex molecules into smaller building blocks all with the same connector piece. They can then be joined together with one simple reaction in a manner similar to children's building blocks.

1

Noise-cancelling windows

IF YOU HAVE loud neighbours, this may be just what you need: double-glazed windows that block out noise. Created at Mokpo National Maritime University, South Korea, the technology uses an array of resonance chambers that trap sound waves. The waves bounce around and eventually cancel one another out.

The windows can block traffic noise, screaming...

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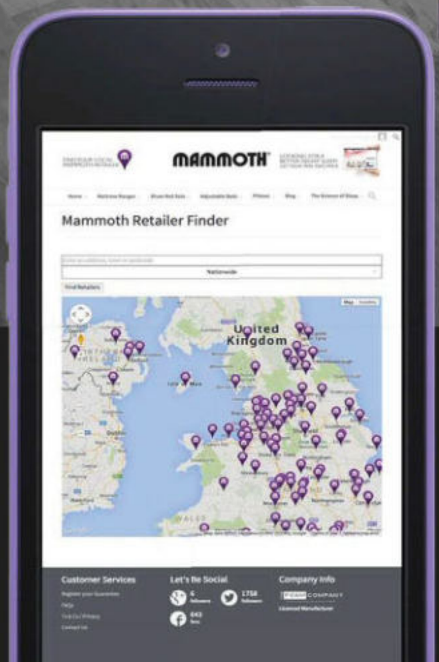
*www.mammothmattress.co.uk/sleep-research



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Test drive a Mammoth mattress at your local stockist,
Visit **www.mammothmattress.co.uk**
Click on our retailer finder & request a free info pack.

INSIDE SCIENCE

ROBERT MATTHEWS

Economists: dial back the maths and go back to basics

MAY IS MY favourite month of the year, as it's pretty much always warm and sunny. That guarantees this May will be rubbish, of course. But if there's one thing worse than a wrong prediction, it's a prediction that proves right for the wrong reason. This leads to misplaced trust.

People have been falling for such predictions for years – 2,600 years, to be exact. In May 585BC the Lydians and the Medes were killing each other, as they had done for years. Suddenly, something startling happened: a cosmic prediction came true.

The Greek philosopher Thales of Miletus had publicly warned that an eclipse of the Sun would darken the heavens, and on 28 May that's exactly what happened. Apparently, it so spooked the commanders of the two armies that they stopped, signed a peace treaty and went home.

Exactly how Thales made his prediction isn't clear. He may have known something about the laws governing eclipses. But some historians suspect he used a dodgy 'rule' that held true at the time, but never worked again. Tellingly, there's no record of Thales repeating his success.

Perhaps we should hail Thales as a pioneer of the art of being right for the wrong reasons. It's an art that flourishes to this day, and nowhere more so than in economics. From the risible attempts to predict inflation rates, to the failure of Nobel prizewinners to spot the global recession even when it was happening, the term 'economic science' is a great oxymoron of our time.

Whether we're talking about economics or eclipses, predictions should be made with care

> **"Darwin showed that even earthworms have figured out what economists struggle with: it's impossible to predict the future"**

To be fair, what economic science seeks to do is far harder than anything attempted by, say, physicists. Economists try to understand incredibly complex, non-linear systems of interconnected devices known as humans. Economists use ever more complex maths in the hope that it will bring them the success of 'hard sciences', but this has been their biggest mistake. They've just ended up being wrong much of the time or – worse – they've occasionally been right for the wrong reasons.

Clearly, economics needs a makeover. Here's my proposal. First, and most obviously, dial down the maths: it may look impressive, but too often it conceals dangerous over-simplification. Illustrious economists like John Maynard Keynes, Friedrich Hayek and Hyman Minsky were critical of the 'mathematisation' of the subject. They preferred to capture complex phenomena in words and imagery rather than equations. This was also the approach used by one of the greatest of all real scientists: Charles Darwin. Darwin was a meticulous observer with a genius for spotting telling facts; he created the theory of evolution without the use of heavy maths. Having no numerical ability, he had no choice but to resort to detailed accounts of his ideas, rather than mathematical models.

But economists should do more than merely emulate Darwin's approach: they too should become meticulous observers of the natural world. Darwin showed that even earthworms have figured out what economists struggle with: it's impossible to predict the future. Instead, organisms use diversity to increase their chances of survival. Darwin didn't need fancy maths to prove why diversity works – the success of life on Earth is compelling enough. It's time that economists swapped equations for broad-brush insights drawn from the natural world. If they did, I'm almost willing to predict they'd see their stock rise dramatically. Almost. ■

ROBERT MATTHEWS is Visiting Reader in Science at Aston University, Birmingham

ILLUSTRATOR: MATT MURPHY

Jeep
THERE'S ONLY ONE

COULD IT BE ANY MORE PERFECT?

There's not a single cloud in the sky and yet it's the Jeep Grand Cherokee that really shines. With its dynamic looks, luxurious interior, innovative technologies and strong, yet efficient engines things really don't get any better. Perhaps that's why it's the most awarded SUV ever.* And should the weather take a turn for the worse, you can always turn on the heated seats.^

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Model shown is a new Jeep Grand Cherokee 3.0 litre V6 Summit. OFFICIAL FUEL CONSUMPTION FIGURES FOR THE NEW 2014 JEEP® GRAND CHEROKEE DIESEL RANGE IN MPG (L/100KM): EXTRA URBAN 43.5 (6.5), URBAN 30.4 (9.3), COMBINED 37.7 (7.5), CO_2 EMISSIONS: 198 G/KM. Fuel consumption and CO_2 figures are obtained for comparative purposes in accordance with EC directives/regulations and may not be representative of real-life driving conditions. Factors such as driving style, weather and road conditions may also have a significant effect on fuel consumption. *Claim relates to the Jeep Grand Cherokee nameplate over its lifetime. ^Excludes Laredo model. Specifications are correct at time of going to press (03/15). Please visit jeep.co.uk for latest information. Jeep® is a registered trademark of FCA US LLC.

INTO THE FUTURE

STEPHEN BAXTER

Does religion have a future?

EASTER FALLS IN April this year, and is the most significant Christian festival. But according to recent surveys – and despite all those Easter eggs – less than half of Britain's population call themselves religious. We aren't alone, either. A decade ago, about 75 per cent of people around the world called themselves religious; that number is now down to around 60 per cent. It may not feel like it when we watch the news of religious conflicts in the Middle East and elsewhere, but the world is becoming more secular.

So does religion have a future? It certainly has a deep past. Receptivity for religious ideas – part of what is called 'cognitive by-product theory' by scientists – may even have had an evolutionary advantage. When predators hunted us, we may have become hyper-receptive to the idea that events in the environment are caused by minds. If you're not sure whether the rustle you hear is the random blowing of a leaf or the footpad of a leopard, it's better to err on the side of caution. Later, the idea of gods and an afterlife may have arisen to help us cope with a dangerous, unpredictable world, and a knowledge of our own mortality. Astute rulers may have observed that religious systems that involve constant surveillance by vengeful gods make a population easier to control.

Could humanoid robots start to erode religious values?

But like other aspects of our culture, such as toolmaking and language, religion no longer seems an exclusively human trait. There is evidence that the Neanderthals created ornaments and used ochre, a natural pigment commonly used by early humans for body painting. These elements point to ritual behaviour, and a belief in realms of existence beyond the physical world.

Maybe a sense of the religious extends even beyond the human lineage. In a recent book, cetologists Hal Whitehead and Luke Rendell argue that whales and dolphins perform rituals over the dead and exhibit grief.

So, religion has a deep past – but today it throws up novel dilemmas. In 1971, astronaut David Scott left a Bible on the Moon. This evoked protests from atheist activists because Apollo was a federal government project. Today, there are plans to store more religious texts and artefacts on the Moon – including the Jewish Sefer Torah and the Hindu Vedas – as part of a wider scheme to create an offworld archive of Earth's treasures.

> **"Which is better: to pray for an end to a plague, or to search scientifically for vaccines and antidotes?"**

Meanwhile, new medical technologies have thrown up religious dilemmas, with the main concern being whether respect for human life is maintained. An evangelical seminary in Matthews, North Carolina, is debating the ethical implications of humanoid robots. In Christian tradition, Jesus adopted human form – the use of such robots may erode the value that society places on that form.

What of the future? There are plenty of arguments that secularism is a good thing for modern humanity. Which is better: to pray for an end to a plague, or to search scientifically for vaccines and antidotes? But why should secularism be on the rise today? Maybe we just don't need religion any more. The most secure societies, such as those found in Scandinavia, are shown to be the most irreligious. Conversely, religious attendances rose sharply in Christchurch, New Zealand, after the 2011 earthquake. It is a gruesome irony that a positive future for religion may rest on a calamitous future for mankind.

And there's always the possibility that religions arise because a god or gods actually exist. ■

STEPHEN BAXTER is a science fiction author who has written over 40 books. His latest is *Ultima*, published by Orion

ILLUSTRATOR: ANDY POTTS

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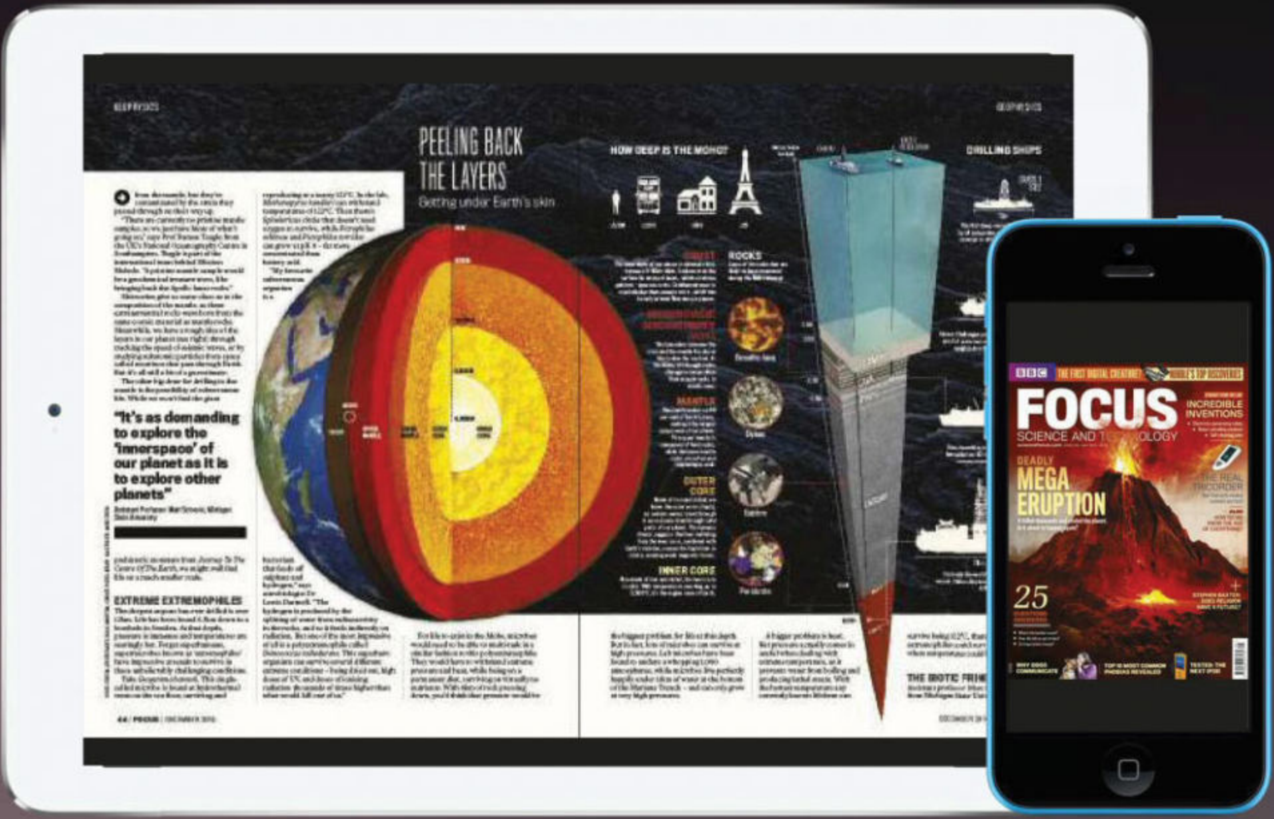

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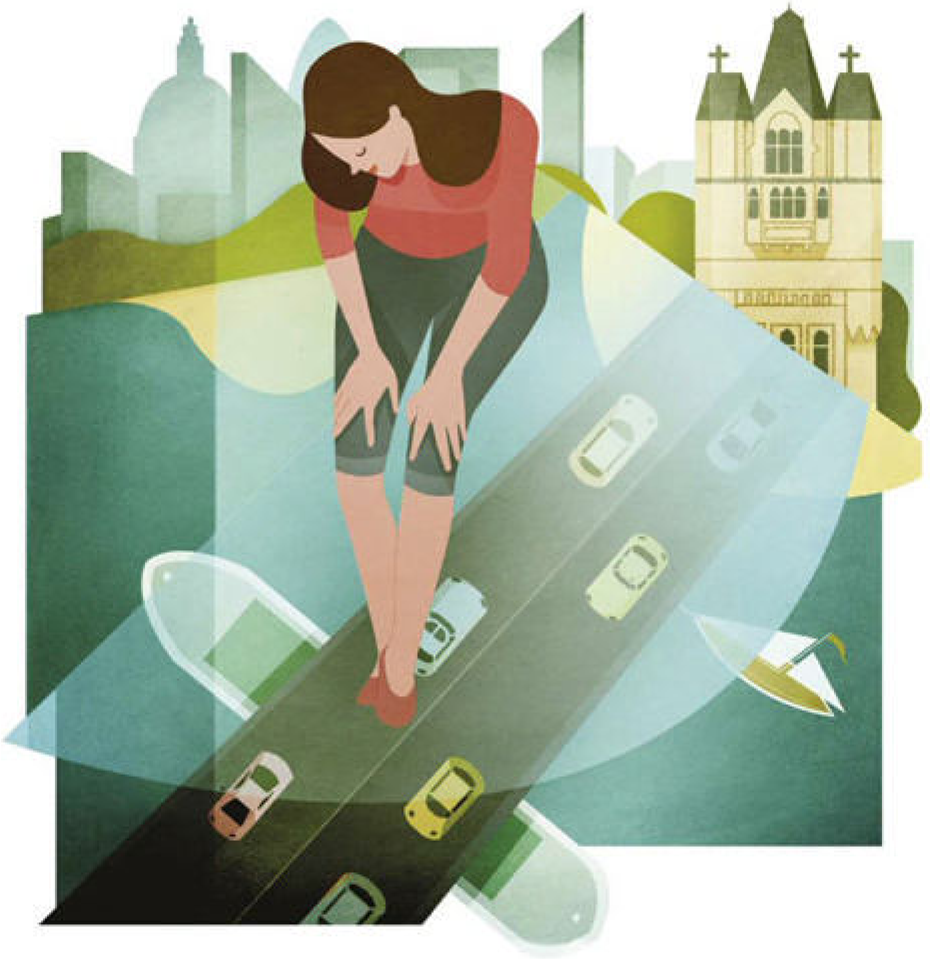
FOCUS
SCIENCE AND TECHNOLOGY

EVERYDAY SCIENCE

HELEN CZERSKI

Walking on ‘thin air’ is unnerving, but helps us understand how light works



AN EXUBERANT TODDLER gallops happily across the rectangle and pauses in the middle for some exploratory jumping before his dad ushers him away. A young couple refuse to venture across it and instead sit nervously at the edge, taking selfies with the rectangle in the background. What’s weird is that it’s only a footbridge, and there’s nothing really unusual about the rectangle in the middle. It’s made of perfectly robust material, just like the rest of the bridge. It’s just that visible light happens to pass straight through it.

I’m standing on the walkway across the top of Tower Bridge in London, looking down through the glass floor to the road and the river below. I can stand with one foot on the glass and one foot on the metal beside it. Atoms hold up one foot, and atoms hold up the other foot. But standing on one side of that line is scary. Is that justified?

We assume that ‘stuff’ should interfere with light, and so it seems obvious that we can see it. But the more interesting question is: why does matter bother light at all? After all, we know that atoms are mostly free space, each one a tiny dense nucleus chaperoned by a sprinkling of distant electrons. There’s loads of space for a passing light ray to zoom right through, and lots of them do. As I walk through the sightseers on the bridge, radio waves and Wi-Fi signals are whooshing straight through me. When you consider the entire electromagnetic spectrum, I’m almost completely see-through. There’s just this funny little bit in the middle where that’s not true, and it gives us all the visual richness we take for granted.

I can see Tower Bridge for two reasons. One is that my eyes only see photons that have the right energy to play bumper cars with the electrons in most materials. Light is absorbed and reflected as the electrons get shuffled around, and that only happens at a very narrow range of wavelengths – the visible part of the spectrum. The second reason is that if a light wave meets an obstacle that’s about the same size as its wavelength, it’s likely to be deflected. The small-scale structure of the object can make it visible, whatever substance it is made of.

> **“When they build the first completely transparent building, I will be up there, jumping with glee like the toddler”**

The bouncing toddler knows none of this. But he is perfectly safe. It just so happens that those two reasons don’t apply to glass and they’re not directly related to its strength. The atoms in glass are jumbled up without any regular structure. This changes the energy that’s needed to shuffle electrons, so that instead of absorbing visible light, glass absorbs the more energetic UV light. Visible light goes straight through, because there’s no reason for it not to. And because of the fluid-like structure of the atoms, there are no boundaries or pores or cracks in the glass, so light doesn’t get scattered either.

Standing on the glass walkway, looking down, I can actually see that this is a flawless material. You’d think that might be more reassuring than standing on an opaque one, without any clues to its structural integrity. The expression on the face of one woman edging around the glass while trying not to look down suggests that this is not the case.

The illusion of walking on nothing is unnerving. But it’s also a lot of fun because it reminds us to ask why we can see anything, and what our sight is really telling us. When they eventually build the first completely transparent building, I will be up there, jumping with glee like the toddler, and admiring a new view of our world. ■

DR HELEN CZERSKI is a physicist, oceanographer and BBC science presenter whose most recent series was *Super Senses*

ILLUSTRATOR: ANDREW LYONS

FOCUS READER SURVEY

We're always looking for ways to improve *BBC Focus* and your views are invaluable in helping us shape its content and development. As well as providing us with information about the best editorial direction, the results of reader surveys help us work out what sort of reader offers, advertising and promotions are most relevant to you. In short, the more we know about your interests, likes and dislikes, the more enjoyable we can make *BBC Focus* for you.

Fill in the form below or complete it online at www.sciencefocus.com/readersurvey

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A. MAGAZINE READING BEHAVIOUR

1. How often do you read *BBC Focus*?
Always – I subscribe ☐ 1
Always – every issue, but I don't subscribe ☐ 2
Quite often – once every 2-3 issues ☐ 3
Occasionally – once every 4-13 issues ☐ 4
This is my first issue ☐ 5

2. How long have you been reading *BBC Focus* for?
Less than a year (skip Q3a and Q3b) ☐ 1
Between 1 and 2 years ☐ 2
Between 2 and 5 years ☐ 3
Between 5 and 10 years ☐ 4
More than 10 years ☐ 5

3a. Compared to your purchasing habits a few years ago, are you buying *BBC Focus*:
More often ☐ 1
Less often ☐ 2
Same as always (skip Q3b) ☐ 3

3b. Please explain why you are buying *BBC Focus* more or less often now?

....

4. On average, how long do you spend reading an issue of *BBC Focus*?
Under 30 minutes ☐ 1
Between 30 minutes and 1 hour ☐ 2
Between 1 and 2 hours ☐ 3
Between 2 and 3 hours ☐ 4
Between 3 and 4 hours ☐ 5
Between 4 and 5 hours ☐ 6
More than 5 hours ☐ 7

5. On average, in the past year, how many other people have read or looked at your copy of *BBC Focus* for longer than a couple of minutes?
Nobody else ☐ 1
1-2 people ☐ 2
3-4 people ☐ 3
5-6 people ☐ 4
7-8 people ☐ 5
More than 8 people ☐ 6

6. Have you ever read the digital edition of *BBC Focus*?
Yes (skip Q8) ☐ 1
No (skip Q7) ☐ 2

7. What were the reason(s) you chose to read the magazine as a digital edition? *Please select all that apply.*
It's really handy on the move ☐ 1
It's more environmentally friendly ☐ 2
It's cheaper than the print version ☐ 3
It's easier to read ☐ 4
I like the digital-only content ☐ 5
The photography looks so much better than in print ☐ 6
It's easy to click on the links ☐ 7
Other (please specify) ☐ 8

....

8. Why haven't you read *BBC Focus* as a digital edition? *Please select all that apply.*
I'm a print subscriber ☐ 1
Didn't know about the digital edition ☐ 2
Prefer to have the paper version ☐ 3
It's not different enough to the print version ☐ 4
I don't have a tablet or ereader ☐ 5
I can't find it in the app store ☐ 6
I read my friend's copy of the magazine ☐ 7
The file size is too big ☐ 8
There's no print and digital combined price ☐ 9
Other (please specify) ☐ 0

....

9. Would you be interested in receiving a more regular digital edition of *BBC Focus*, such as a weekly version?
Yes ☐ 1
No ☐ 2
Maybe ☐ 3

B. SCIENCE AND TECHNOLOGY INTERESTS

10. How would you best describe your interest in science and technology? *Please select all that apply.*
General interest ☐ 1
Enthusiast ☐ 2
Student ☐ 3
Teacher/lecturer ☐ 4
Work-related interest ☐ 5
Other (please specify) ☐ 6

....

11. Which of the following apply to your interest in science and technology? *Please select all that apply.*
I want to learn more about the world around me ☐ 1
I like to learn about new discoveries/breakthroughs ☐ 2
I like to understand how science/technology developments apply to everyday life ☐ 3
I want to understand what the future holds ☐ 4
I find science/technology fun ☐ 5
Other (please specify) ☐ 6

....

12. How interested are you in reading about these topics? *Please select one answer per row.*

Topic	Very interested 1	Quite interested 2	Ambivalent 3	Not that interested 4	Not at all interested 5
Artificial intelligence	☐	☐	☐	☐	☐
Robotics	☐	☐	☐	☐	☐
Future technology	☐	☐	☐	☐	☐
Evolution	☐	☐	☐	☐	☐
Genetics	☐	☐	☐	☐	☐
Personal health	☐	☐	☐	☐	☐
Medicine	☐	☐	☐	☐	☐
Psychology	☐	☐	☐	☐	☐
Natural world	☐	☐	☐	☐	☐
Climate change/environment	☐	☐	☐	☐	☐
History of science	☐	☐	☐	☐	☐
Gadget reviews	☐	☐	☐	☐	☐
Archaeology	☐	☐	☐	☐	☐
Palaeontology	☐	☐	☐	☐	☐
Geology	☐	☐	☐	☐	☐
Particle physics	☐	☐	☐	☐	☐
Space/astronomy	☐	☐	☐	☐	☐
Materials science	☐	☐	☐	☐	☐
Neuroscience	☐	☐	☐	☐	☐

13. Here are some things that other people have said about *BBC Focus*. How much do you agree/disagree with the following statements?

Statement	Agree strongly 1	Agree slightly 2	Neither agree nor disagree 3	Disagree slightly 4	Disagree strongly 5
It's written by experts in their field	☐	☐	☐	☐	☐
The design is really appealing	☐	☐	☐	☐	☐
I like the broad range of content	☐	☐	☐	☐	☐
It's for people with a good knowledge of science	☐	☐	☐	☐	☐
I prefer the in-depth articles	☐	☐	☐	☐	☐
I prefer the short, snappy articles	☐	☐	☐	☐	☐
It introduces me to interesting ideas/discoveries	☐	☐	☐	☐	☐
It explains complex ideas	☐	☐	☐	☐	☐
It's full of incredible facts	☐	☐	☐	☐	☐
It helps me to understand how science/technology will shape the future	☐	☐	☐	☐	☐
It inspires me to learn more	☐	☐	☐	☐	☐

14. What do you think about the level of articles that are featured in *BBC Focus*?
Much too academic ☐ 1
A bit too academic ☐ 2
About right ☐ 3
A bit too simplistic ☐ 4
Much too simplistic ☐ 5

15. What do you think about *BBC Focus* coverage of the following topics?:

Topic	About right 1	Too much 2	Not enough 3
Artificial intelligence	☐	☐	☐
Robotics	☐	☐	☐
Future technology	☐	☐	☐
Evolution	☐	☐	☐
Genetics	☐	☐	☐
Personal health	☐	☐	☐
Medicine	☐	☐	☐
Psychology	☐	☐	☐
Natural world	☐	☐	☐
Climate change/environment	☐	☐	☐
History of science	☐	☐	☐
Gadget reviews	☐	☐	☐
Archaeology	☐	☐	☐
Palaeontology	☐	☐	☐
Geology	☐	☐	☐
Particle physics	☐	☐	☐
Space/astronomy	☐	☐	☐
Materials science	☐	☐	☐
Neuroscience	☐	☐	☐

16. How much did you enjoy this issue of *BBC Focus*?
Very much ☐ 1
Quite a lot ☐ 2
Not very much ☐ 3
Not at all ☐ 4
Didn't read this issue (skip Q17) ☐ 5

17. Listed below are all the articles in this issue of *BBC Focus*. For each item, please tick the column that comes closest to your opinion.

Pg.	Article	Did not read 1	Very interesting 2	Quite interesting 3	Not very interesting 4	Not at all interesting 5
8	MegaPixel	☐	☐	☐	☐	☐
12	Reply	☐	☐	☐	☐	☐
15	Discoveries	☐	☐	☐	☐	☐
27	Robert Matthews column	☐	☐	☐	☐	☐
29	Stephen Baxter column	☐	☐	☐	☐	☐
32	Helen Czerski column	☐	☐	☐	☐	☐
35	Hubble's top 10 discoveries	☐	☐	☐	☐	☐
47	Meet the first digital life form	☐	☐	☐	☐	☐
54	Can we make a tricorder?	☐	☐	☐	☐	☐
60	Deadly mega eruption	☐	☐	☐	☐	☐
67	Q&A	☐	☐	☐	☐	☐
71	Bill McGuire column	☐	☐	☐	☐	☐
77	Tech hub: Pebble Time	☐	☐	☐	☐	☐
79	Bill Thompson column	☐	☐	☐	☐	☐
81	Appliances of science	☐	☐	☐	☐	☐
82	Ultimate test: high-res audio	☐	☐	☐	☐	☐
86	How do we know… the age of things	☐	☐	☐	☐	☐
93	To do list: pick of the month	☐	☐	☐	☐	☐
94	To do list: watch	☐	☐	☐	☐	☐
96	To do list: listen/touch	☐	☐	☐	☐	☐
97	To do list: visit	☐	☐	☐	☐	☐
98	To do list: read	☐	☐	☐	☐	☐
105	Mindgames: crossword	☐	☐	☐	☐	☐
106	Hollywood science	☐	☐	☐	☐	☐

18. On average, how regularly do you read the technology reviews in *BBC Focus*?
Every issue I buy ☐ 1
Some issues I buy ☐ 2
Rarely ☐ 3
Never ☐ 4

19a. Compared to a year ago, how do you feel about *BBC Focus* now?
The magazine has improved considerably ☐ 1
The magazine has improved a little ☐ 2
It is more or less the same as a year ago (skip Q19b) ☐ 3
The magazine has got a little worse ☐ 4
The magazine has got considerably worse ☐ 5
I haven't been reading the magazine that long (skip Q19b) ☐ 6

19b. Please tell us the reasons why you think the magazine has improved/got worse:

....

Reader Survey

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20. How often do you look at the adverts in *BBC Focus*?
Always ☐ 1
Sometimes ☐ 2
Rarely ☐ 3
Never ☐ 4

21. Has reading *BBC Focus* ever led you to do any of the following? *Please select all that apply.*
Visiting sciencefocus.com ☐ 1
Attending an event/exhibition ☐ 2
Buying a tech product/gadget ☐ 3
Buying another product ☐ 4
Looking for further information on a product seen in the magazine ☐ 5
Referring to, or discussing, an advert/article with someone else ☐ 6
Visiting a company's website ☐ 7
Contacting an advertiser ☐ 8
Researching an article further ☐ 9
Taking a course ☐ 0

22. Do you have any other comments on *BBC Focus*?

....

23. On average, how often do you visit the *BBC Focus* website (sciencefocus.com)?
More than once a day ☐ 1
Once a day ☐ 2
About 2-3 times a week ☐ 3
Once a week ☐ 4
Once every couple of weeks ☐ 5
Once a month ☐ 6
Every 2-3 months ☐ 7
Less often ☐ 8
Never used it ☐ 9

C. WIDER INTERESTS/BEHAVIOUR

24. How often do you read the following magazines?

Magazine	Always, subscribe 1	Always, every issue but I don't subscribe 2	Quite often 3	Occasionally 4	Only read one issue 5
Wired	☐	☐	☐	☐	☐
Stuff	☐	☐	☐	☐	☐
T3	☐	☐	☐	☐	☐
How It Works	☐	☐	☐	☐	☐
Wonderpedia	☐	☐	☐	☐	☐
New Scientist	☐	☐	☐	☐	☐
Astronomy Now	☐	☐	☐	☐	☐
BBC Sky At Night Magazine	☐	☐	☐	☐	☐
Scientific American	☐	☐	☐	☐	☐

25. Have you ever attended a science or technology themed event? *Please select all that apply.*
Evening lecture ☐ 1
One day conference/seminar ☐ 2
Science/tech exhibition e.g. Gadget Show Live ☐ 3
Science/tech festival e.g. Cheltenham Science Festival ☐ 4
I have not attended a science/tech themed event (skip Q26) ☐ 5

26. Please tell us the reasons why you chose to attend these events? *Please select all that apply.*
I live locally to the event ☐ 1
It covered subjects I'm interested in ☐ 2
It was related to a topic that I'm studying ☐ 3
It encouraged children/grandchildren to be interested ☐ 4
It encouraged active participation ☐ 5
To hear a specific speaker that I like ☐ 6

27. Thinking about new technology and gadgets, which of the following statements best describes yourself?
I am normally one of the first to get the latest tech/gadgets, and like to keep up with developments as they happen ☐ 1
I like to follow the latest tech/gadgets, but tend to wait before I decide whether to buy into products ☐ 2
I don't have much interest in buying the latest tech/gadgets. I buy technology that suits my needs rather than getting the latest product ☐ 3

28. How interested are you in wearable technology (smart watches, fitness trackers, etc.)?
Very interested ☐ 1
Quite interested ☐ 2
Ambivalent ☐ 3
Not that interested ☐ 4
Not at all interested ☐ 5

29. Have you taken, or are you interested in taking, any of the following qualifications?

	Achieved 1	Interested in taking 2	Not interested in taking 3
Science/tech subject GCSE	☐	☐	☐
Science/tech subject A Level	☐	☐	☐
Science/tech bachelor's or master's	☐	☐	☐
Science/tech doctorate or equivalent	☐	☐	☐
Science/tech evening course	☐	☐	☐
Science/tech short course or non-formal qualification	☐	☐	☐

30. Have you been on or are you interested in any of the following types of science-related travel?

	Been on before 1	Not been on, but am interested 2	Not been on and not interested 3
Astronomy breaks	☐	☐	☐
Visiting natural phenomena e.g. Northern Lights	☐	☐	☐
Visiting places of scientific interest e.g. Galapagos Islands	☐	☐	☐
Visiting National Parks/conservation areas	☐	☐	☐
Seeing wildlife spectacles	☐	☐	☐
Scientific expeditions	☐	☐	☐
Science summer school/retreat	☐	☐	☐

D. ABOUT YOU

31. Are you?
Male ☐ 1
Female ☐ 2

32. Which age group are you in?
Under 16 ☐ 1
16-24 ☐ 2
25-34 ☐ 3
35-44 ☐ 4
45-54 ☐ 5
55-64 ☐ 6
65+ ☐ 7

32. What is your current working status?
Employed full-time ☐ 1
Employed part-time ☐ 2
Studying full-time ☐ 3
Studying part-time ☐ 4
Retired ☐ 5
Not working ☐ 6

33. Which of these best describes the main wage earner's occupation? If retired, please tick the box describing their former occupation.
Professional ☐ 1
Senior management ☐ 2
Middle management ☐ 3
Small business owner ☐ 4
Junior management ☐ 5
Office/clerical ☐ 6
Skilled manual ☐ 7
Semi-skilled manual ☐ 8
Unemployed ☐ 9
Student ☐ 0

34. What is your household income before tax?
Under £20,000 ☐ 1
£20,000-£29,999 ☐ 2
£30,000-£39,999 ☐ 3
£40,000-£49,999 ☐ 4
£50,000-£69,999 ☐ 5
£70,000-£99,999 ☐ 6
£100,000-£149,999 ☐ 7
£150,000+ ☐ 8
Prefer not to say ☐ 0

35. Is your home?
Mortgaged ☐ 1
Owned outright ☐ 2
Rented ☐ 3
Other ☐ 4

Thanks for completing our survey. So that you can be entered into our prize draw for your chance to win one of five £100 Amazon vouchers, please fill in your details below:

Name: ....

Email: ....

Telephone number: ....

Finally, would you be happy to be contacted about any further research we are running for *BBC Focus* in the future?
Yes ☐ 1
No ☐ 2

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HUBBLE'S TOP 10 DISCOVERIES

The Hubble Space Telescope has been observing the Universe for a quarter of a century. **Amy Tyndall** takes a look at some of its most incredible discoveries

TWENTY-FIVE YEARS ago, one of the most famous and awe-inspiring pieces of technology – The Hubble Space Telescope – was launched.

Hitching a ride with the Space Shuttle Discovery in 1990, Hubble was placed in low-Earth orbit, where it has been continuously observing the night sky ever since. Observations have been carried out across all wavelengths of light, from ultraviolet to infrared, which have given astronomers an unprecedented window on the Universe.

But what have they learned from its breathtaking pictures? To find out, we polled 100 professional astronomers around the world, and the results are in…

The Sky at Night
CELEBRATES 25 YEARS OF HUBBLE
BBC FOUR 12 April at 10pm

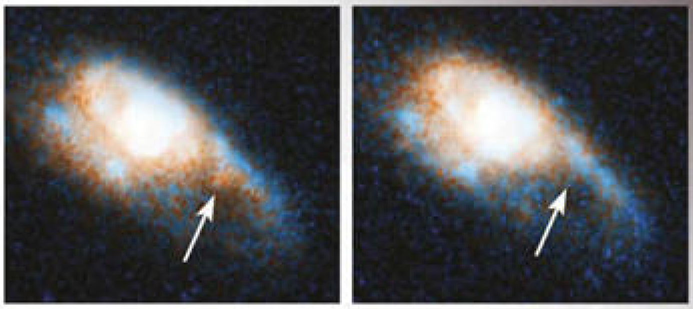
10

CAUSE OF GAMMA-RAY BURSTS

THE FUZZY-LOOKING galaxy to the right was home to one of the most energetic events in the Universe: a gamma-ray burst (GRB). These flashes of gamma-ray radiation are an enigma because they're so rare – a typical galaxy produces only a few every million years. Yet they release as much energy in a few seconds as our Sun does in 10 billion years. On 3 June 2013, a GRB lasting one-tenth of a second occurred, and was spotted by NASA's Swift satellite. When Hubble looked 10 days later, it found an infrared glow where the burst had been. But by 3 July it had faded. This disappearing glow was the dying embers of another kind of cosmic explosion – a kilonova – believed to be the result of extremely dense stars called 'neutron stars' merging. Since the kilonova was found in the same location as the GRB, it was the 'smoking gun' revealing that short GRBs could well be caused in the same way. The kilonova was investigated by Prof Nial Tanvir of Leicester University, who says Hubble played a vital role. "Although Swift discovered this particular short gamma-ray burst, and observations from ground-based telescopes gave us its precise position and distance, Hubble was the only option for seeing the faint kilonova emission."

> "Gamma-ray bursts release as much energy in a few seconds as our Sun does in 10 billion years"

An infrared glow was spotted on 13 June 2013 (left) but had faded by 3 July (right)



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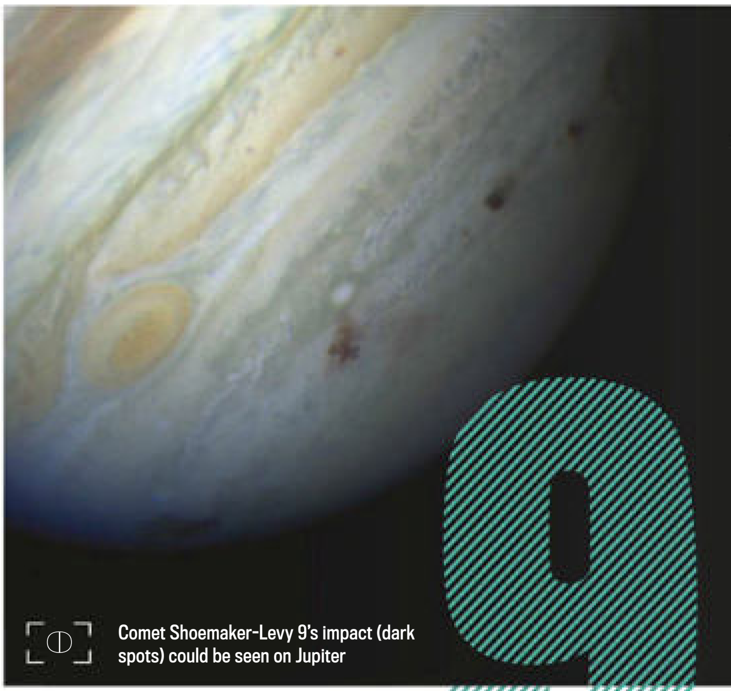

Comet Shoemaker-Levy 9's impact (dark spots) could be seen on Jupiter

HOW PLANETARY COLLISIONS WORK

ON 16 JULY 1994, telescopic eyes were turned on Jupiter as the first of 21 fragments of the broken-up comet, Shoemaker-Levy 9, crashed into the planet. Blotches scarred the atmosphere for a month before fading away.

Hubble's observations provided a wealth of information about Jupiter's atmosphere. "Obvious waves emanated from the largest impacts, like ripples in a pond. From this, we could make deductions about the deep atmosphere and water below the clouds," explains Dr Amy Simon, senior scientist for planetary atmospheres research at NASA Goddard.

While ground-based observatories were also involved, Hubble was the only one that could look across an entire range of wavelengths, irrespective of the time of day or weather conditions. Ultraviolet was particularly important for imaging dust and aerosols whipped up by the impacts. "Hubble observed leftover debris and molecules high in the atmosphere for months, and even years, afterwards," says Dr Simon.

PHOTO: NASA/HUBBLE X3, SCIENCE PHOTO LIBRARY

Protoplanetary discs (like the one in this artist's impression) are where planets are born. They shed light on the early Solar System

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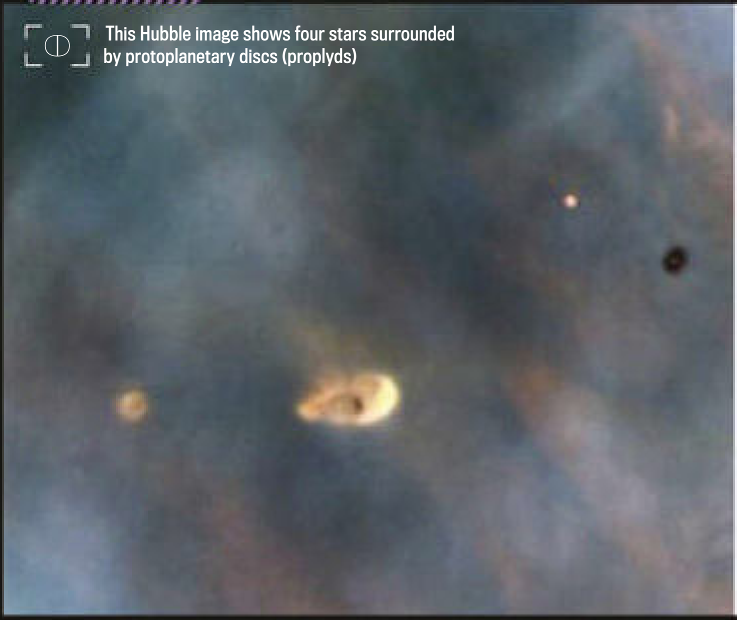
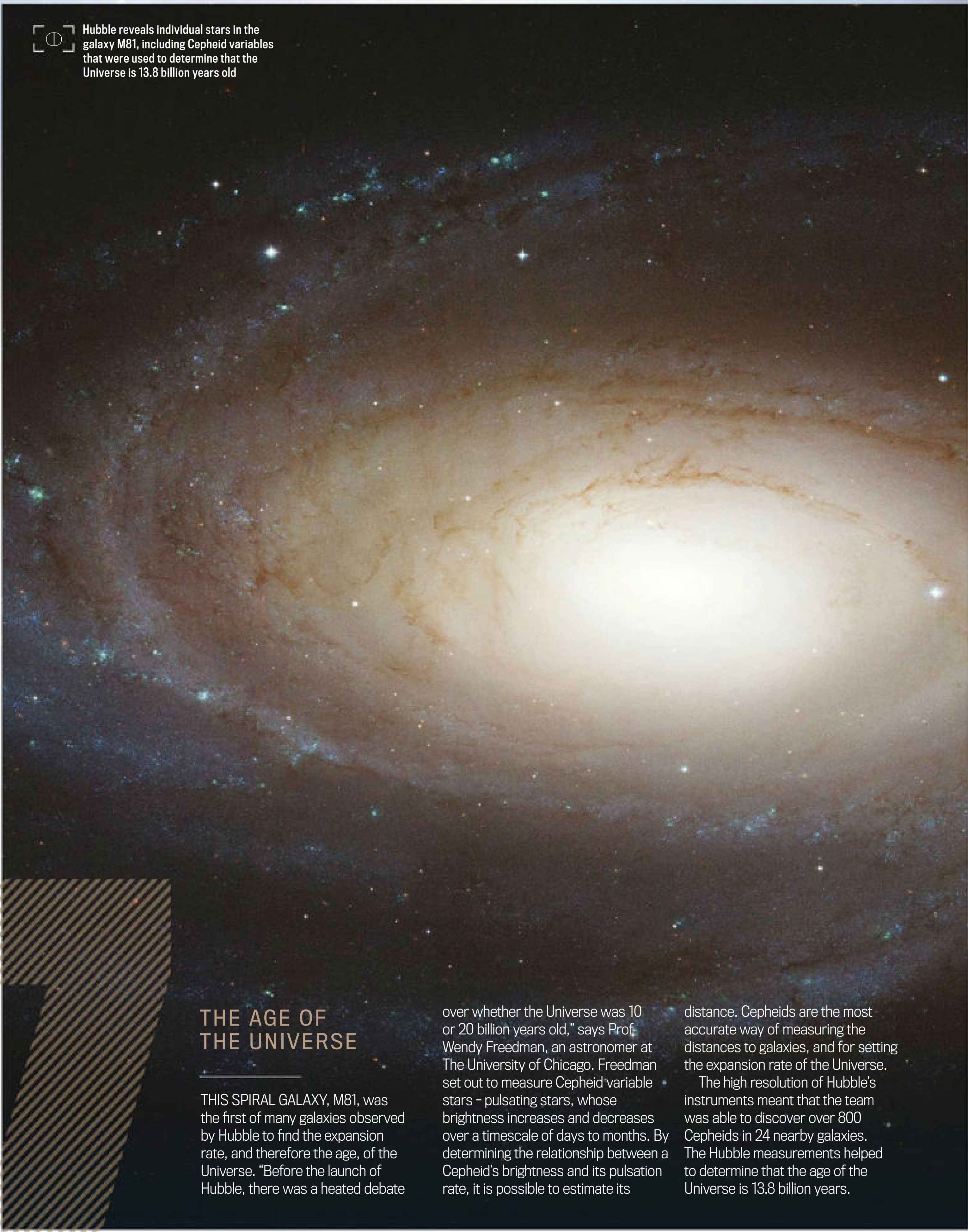


This Hubble image shows four stars surrounded by protoplanetary discs (proplyds)

PROTOPLANETARY DISCS

LOOKING LIKE LITTLE islands, these flat discs of cold dust and gas are left over from the formation of a new star in the Orion nebula. Although part of this material will be lost over time, some will eventually clump together in pebble-sized grains before potentially building up to form a baby planet. As such, they are known as protoplanetary discs, or 'proplyds'. By learning about proplyds, astronomers hope to find out more about the formation of Earth and the other planets. "This what our Solar System looked like in its infancy," says Prof C Robert O'Dell, who made this image. Ground-based telescopes had previously detected the objects, which were initially believed to be stars. The idea that they were discs of material surrounding the star goes back to the 1700s, but confirmation didn't come until the late 1980s, when astronomers managed to detect the disc through observations of its molecules. Hubble provided the breakthrough – directly imaging numerous proplyds for the first time within the Orion nebula.



Hubble reveals individual stars in the galaxy M81, including Cepheid variables that were used to determine that the Universe is 13.8 billion years old

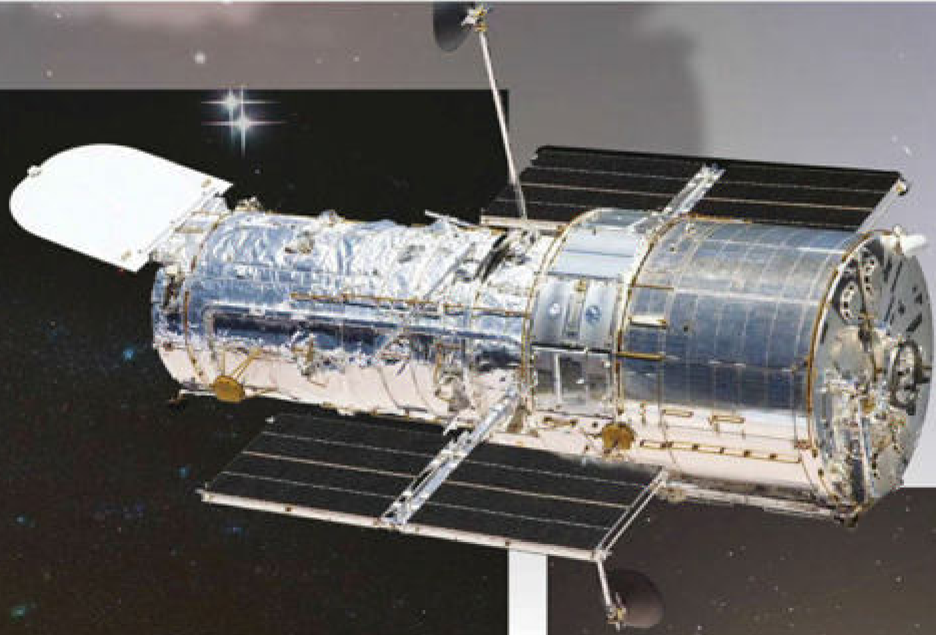
PHOTO: NASA/HUBBLE X3

7

THE AGE OF THE UNIVERSE

THIS SPIRAL GALAXY, M81, was the first of many galaxies observed by Hubble to find the expansion rate, and therefore the age, of the Universe. “Before the launch of Hubble, there was a heated debate over whether the Universe was 10 or 20 billion years old,” says Prof Wendy Freedman, an astronomer at The University of Chicago. Freedman set out to measure Cepheid variable stars – pulsating stars, whose brightness increases and decreases over a timescale of days to months. By determining the relationship between a Cepheid’s brightness and its pulsation rate, it is possible to estimate its distance. Cepheids are the most accurate way of measuring the distances to galaxies, and for setting the expansion rate of the Universe.

The high resolution of Hubble’s instruments meant that the team was able to discover over 800 Cepheids in 24 nearby galaxies. The Hubble measurements helped to determine that the age of the Universe is 13.8 billion years.



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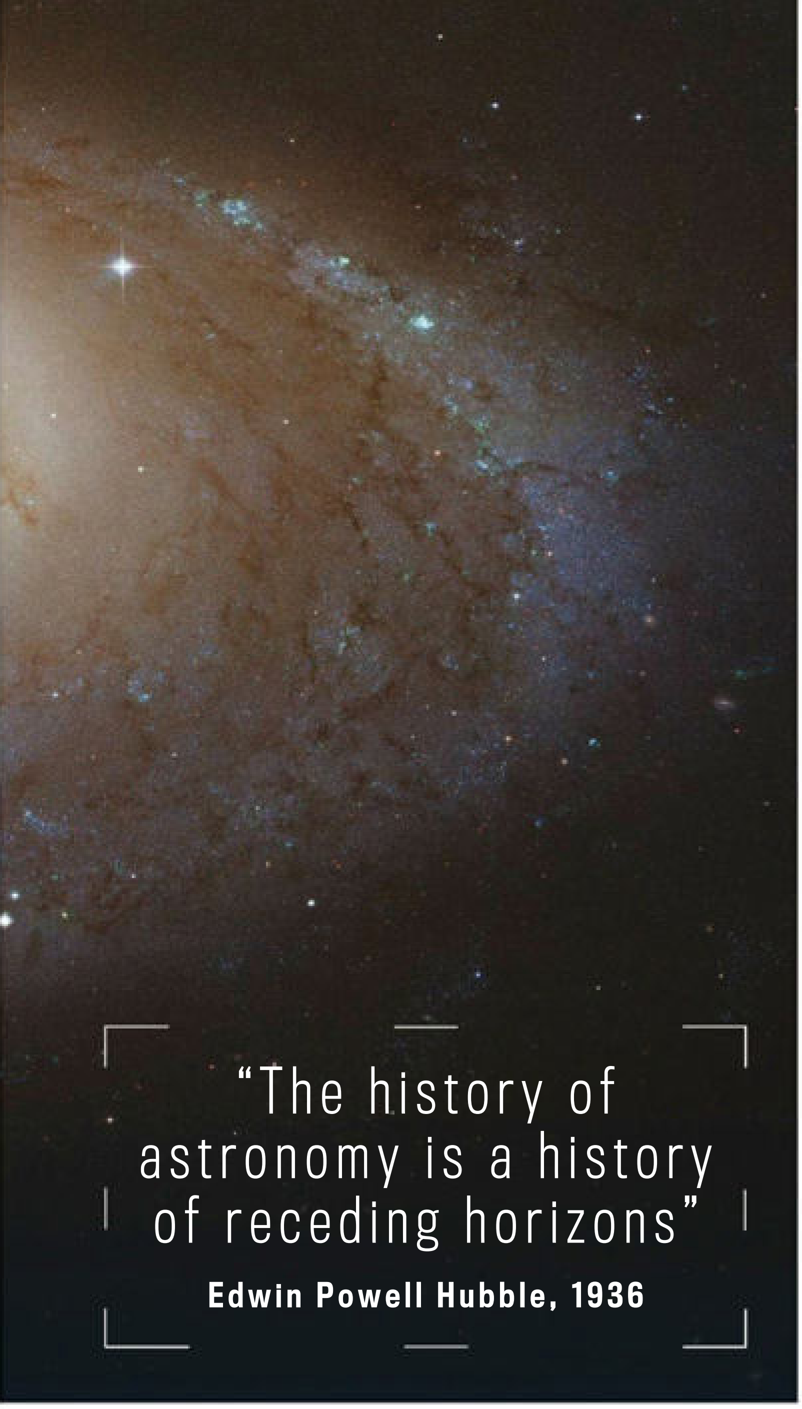
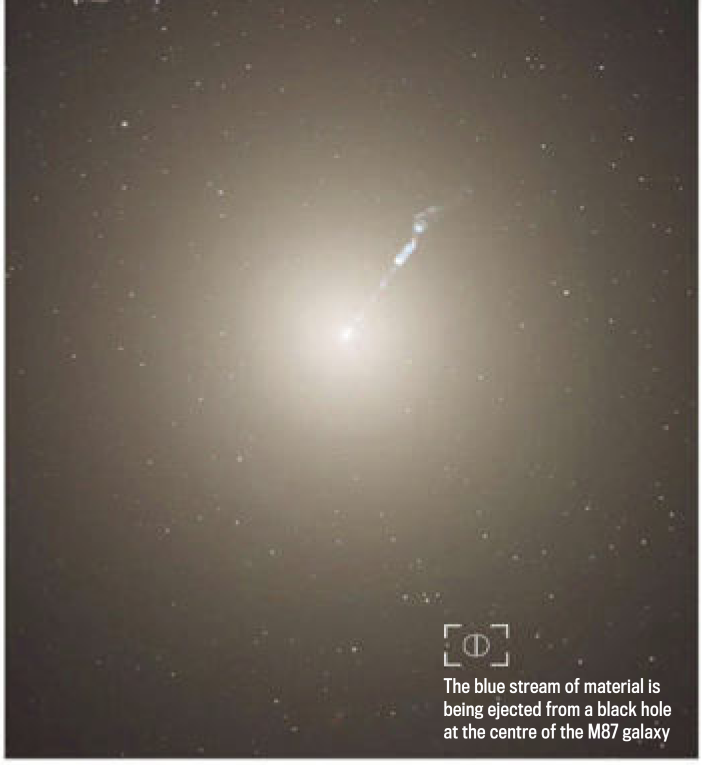


> “The history of astronomy is a history of receding horizons”
>
> **Edwin Powell Hubble, 1936**



The blue stream of material is being ejected from a black hole at the centre of the M87 galaxy

SUPERMASSIVE BLACK HOLES

BLACK HOLES ARE difficult to find. Their intense gravitational force is so strong that not even light can escape their pull, making them ‘invisible’. But by measuring the speed of material that surrounds a black hole, it is possible to calculate its mass using the laws of gravity. If there is more mass than is accounted for by the stars we see, the rest could be due to a black hole. By the early 1990s, it was suspected that a supermassive black hole (SMBH) was at the centre of a handful of galaxies. “Soon after its launch, Hubble confirmed earlier SMBH detections by taking images five times sharper than those obtained from the ground,” explains Dr Marc Sarzi, an astronomer at the University of Hertfordshire. Hubble became known as a ‘black hole hunter’, due to its ability to measure the speed of surrounding gas and stars. Results from its observations were surprising, says Dr Sarzi. “SMBHs have a radius comparable to that of our Solar System, and yet can only directly affect the motion of stars and gas in the very central regions of their host galaxies,” he says. It suggests they evolved together, he explains. “It has turned SMBHs from being exotic curiosities to an integral part of our understanding of galaxy formation.”

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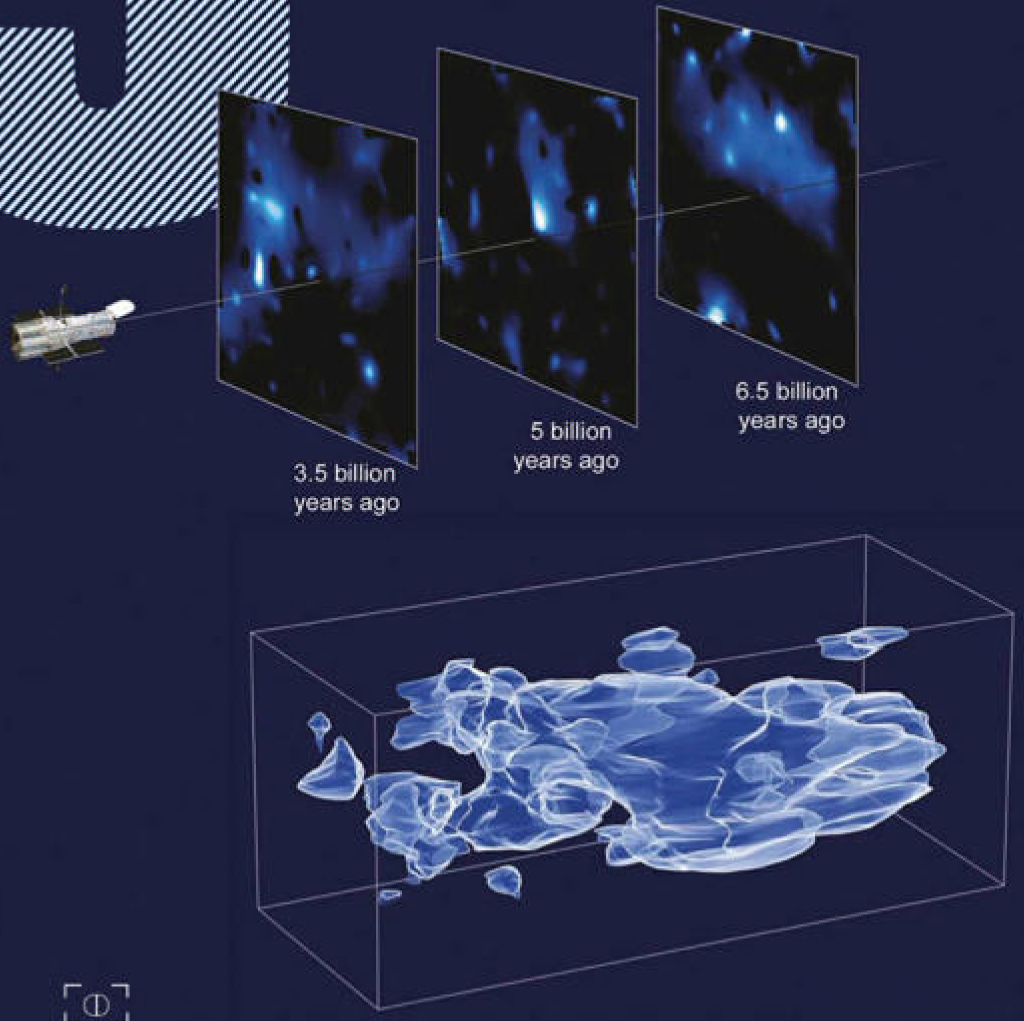


Hubble allowed scientists to create this 3D map of dark matter – the distance from Earth increases from left to right

DARK MATTER

THIS PICTURE REVEALS the presence of something we can't see: 'dark matter'. The galaxies, stars and planets that we *can* see make up just 15 per cent of the Universe's matter. The rest – the other 85 per cent – is dark matter and it neither emits nor absorbs any known wavelength of light. "With this map, we saw for the first time where dark matter is," says Durham University physicist Dr Richard Massey. To construct it, half a million galaxies were observed by Hubble and ground-based telescopes. "When light travels across the Universe, it passes through all the intervening dark matter on its way to us, leaving a telltale imprint of its journey. You can't see such faraway, faint galaxies from Earth because the atmosphere blurs the detail. This is why we needed Hubble," explains Massey. The dark matter bends the light in a 'gravitational lensing' effect, making the galaxies appear distorted. By observing this, it's possible to deduce where dark matter lies. Such a map is fundamental to understanding the Universe's structure, as dark matter acts as 'scaffolding', along which galaxies are assembled. "When the first explorers reached the American West, they sat on a ridge and tried to understand the lie of the land. We were doing the same thing on a new frontier," says Massey.

PHOTO: NASA X2

> "You can't see such faraway, faint galaxies from Earth because the atmosphere blurs the detail"

4

GENERATIONS OF STARS

GLOBULAR CLUSTERS ARE compact crowds of hundreds of thousands of stars bound together by gravity. For many years it was believed that all the stars within must be very similar, having formed close together from the same dusty cloud. But in 2005, Hubble measured the brightness and colours of stars inside the NGC 2808 globular cluster. Only one generation of stars was expected, but three were found.

Dr Giampaolo Piotto was the leader of the team that observed NGC 2808. "With an age up to 13.5 billion years – only 300 million years less than the age of the Universe – globular clusters are a benchmark for cosmology, and represent an ideal laboratory to understand star formation and chemical evolution in the Universe," he explains. What defines the different generations of stars, also known as 'stellar populations', are characteristics such as their chemical composition, age, and their location in the cluster. Hubble's high-resolution images allowed Dr Piotto and his team to look into the densely packed core of NGC 2808 and measure many stars – something that is difficult for ground-based telescopes to do. Hubble's power to observe in both visible and ultraviolet light also made it easier to spot multiple populations of stars and track their evolutionary paths.

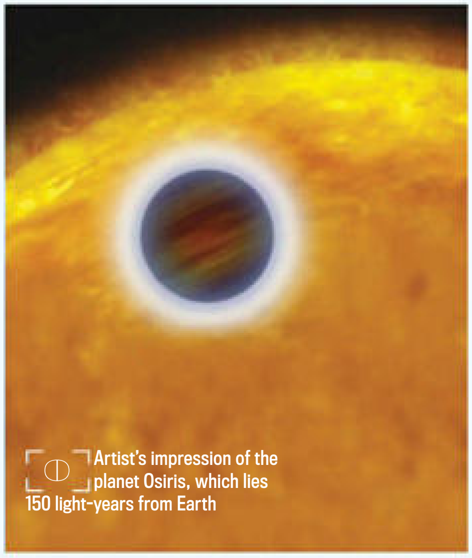
"We have now used Hubble to observe more than 60 globular clusters – almost half the known globular clusters in the Milky Way. Preliminary results show that all have multiple stellar populations," says Dr Piotto.

The NGC 2808 globular cluster contains over one million stars of three different generations

EXOPLANET ATMOSPHERES

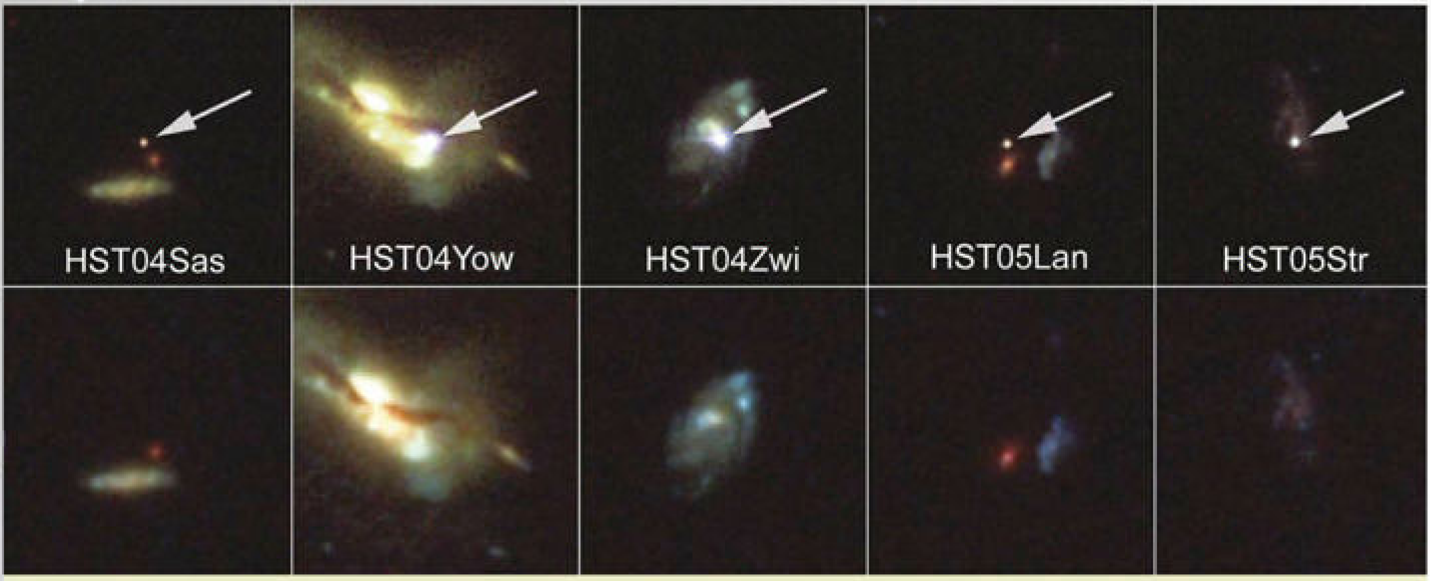
AS OF FEBRUARY 2015, 1,890 planets had been detected orbiting stars other than our Sun. An impressive photo of one of these 'exoplanets' has yet to be taken, but Hubble was first to detect the atmosphere of one of these alien worlds.

HD 209458-b, also known as Osiris, is a planet 150 light-years from Earth. Temperatures reach a scorching 1,100°C as it orbits just 6.4 million kilometres from its parent star. As the orbiting planet moves in front of the star, some of the light passes through the planet's atmosphere. This is analysed by a spectrograph, which is an instrument that splits the light into constituent wavelengths, explains Prof David Charbonneau, leader of the team behind the discovery. "The idea was to gather spectra when the planet was in front of the star and when it moved away. By comparing them, we would search for the appearance of new features when the planet was in transit. This required an extremely stable platform that was free from the absorption effects of our atmosphere. Only Hubble could do it!" In 2001, the procedure revealed signs of sodium – the first atmospheric element detected on a planet outside of our Solar System.



Artist's impression of the planet Osiris, which lies 150 light-years from Earth

"This same method has become the standard means to examine exoplanet atmospheres, and Hubble has now gathered similar data on dozens of worlds," says Charbonneau.



The arrows point to the supernovae; the bottom row shows the galaxies after the stars exploded

2

ACCELERATING EXPANSION OF THE UNIVERSE

THESE GALAXIES, HOSTING energetic supernovae (exploding stars), contributed to one of the most talked-about discoveries in recent years. Not only is the expansion of the Universe accelerating, it is being fuelled by a phenomenon dubbed 'dark energy'.

In 1998, astronomers released new data on how the brightness of supernovae changed over time. It showed that the light coming from the most distant exploding stars was fainter and more stretched (red-shifted) than predicted. It meant that they were further away than astronomers calculated – a result that didn't fit with the existing idea that the tug of gravity was causing the expansion of the Universe to slow down. For the team leading the project, this could only mean one thing: the expansion rate is not slowing at all. It's speeding up.

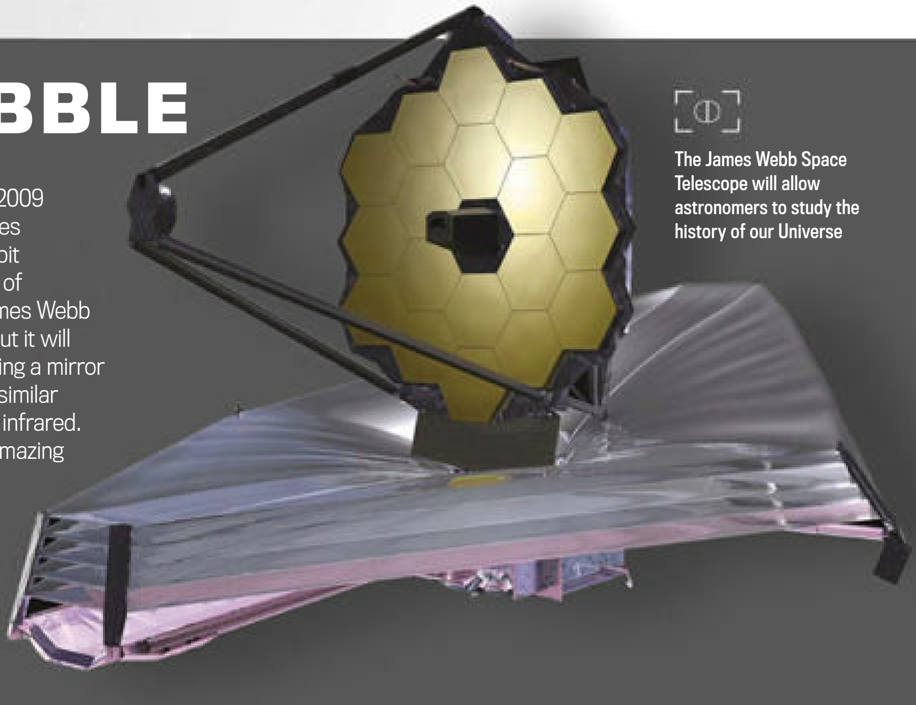
Hubble played a supporting role in this initial discovery by providing data for three of the supernovae that the team wanted to observe, with the rest coming from ground-based telescopes in Chile, Europe and the USA. "This result was so extraordinary that it required extraordinary evidence," explains Dr Adam Riess, one of the three Nobel prize-winning team members for the discovery. "This confirming evidence came from the Hubble Space Telescope."

By finding and precisely measuring another 16 supernovae at distances up to 10 billion light-years away, Hubble was able to confirm not just the acceleration, but that the Universe had indeed been decelerating in earlier times, just as predicted.

But to overcome gravity, something must be giving an opposing, repulsive force as the Universe expands and matter is spread out. This 'something' is dark energy, which makes up approximately 75 per cent of the entire known Universe. Hubble observations showed that this caused the acceleration we see today to begin about five billion years ago.

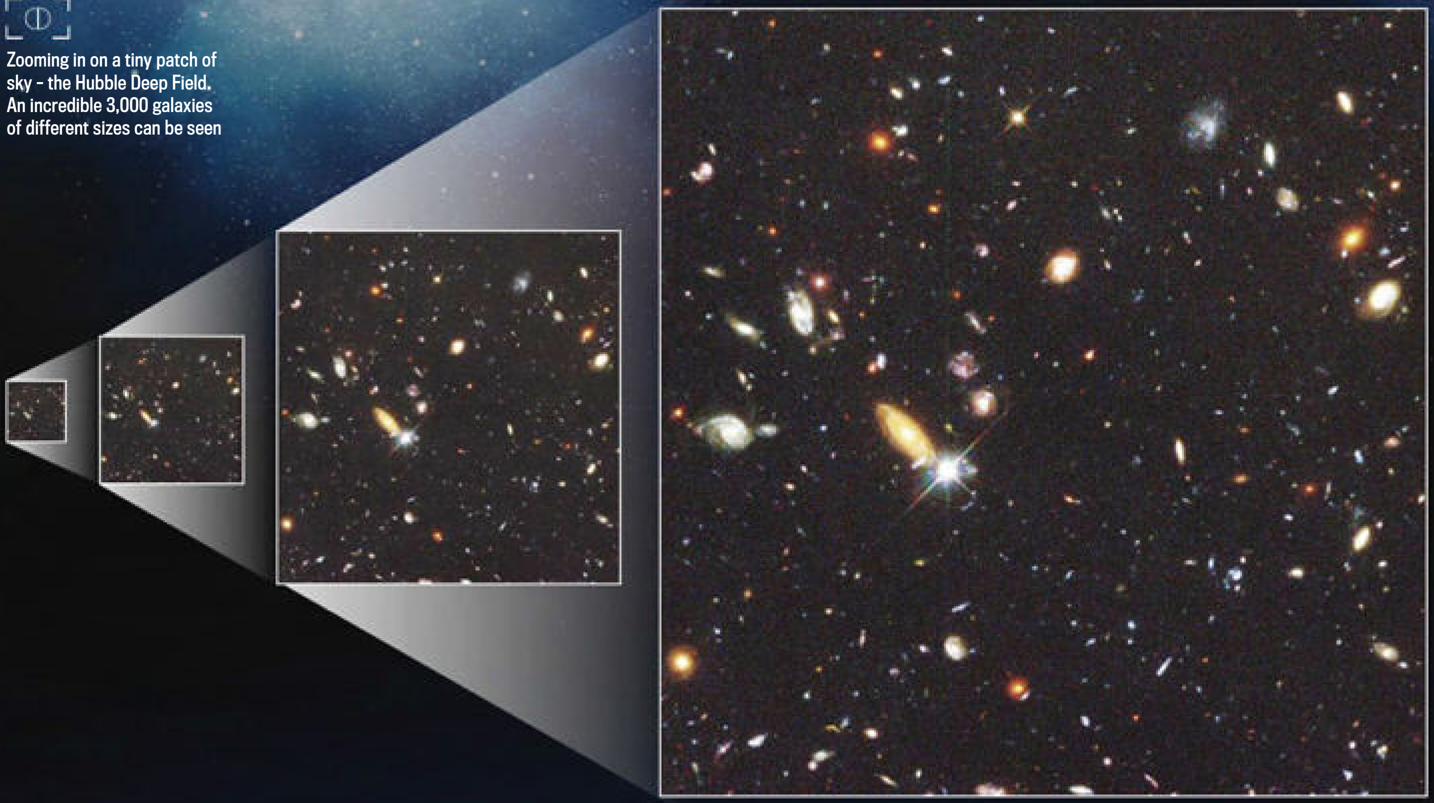
BEYOND HUBBLE

HUBBLE UNDERWENT ITS last servicing mission in 2009 and is expected to remain operational until it degrades around 2020. Hubble will then be sent into a final orbit back down into Earth's atmosphere to end its years of service in a blaze of glory. The highly anticipated James Webb Space Telescope (JWST) is due for launch in 2018, but it will not be a direct replacement for Hubble. Despite having a mirror almost three times as large, JWST will observe at a similar resolution but in a different wavelength of light – the infrared. It will be able to observe cold and dusty objects in amazing detail that previously appeared 'invisible', allowing astronomers to see further out into space, and back in time, than ever before.



The James Webb Space Telescope will allow astronomers to study the history of our Universe

PHOTO: NASA X3



Zooming in on a tiny patch of sky – the Hubble Deep Field. An incredible 3,000 galaxies of different sizes can be seen

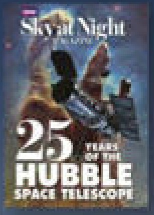
HOW GALAXIES EVOLVE

THIS AWE-INSPIRING image, dappled with beautiful shapes and a whole array of colours, changed the way we think about the distant Universe forever. One of Hubble's most famous images, the Hubble Deep Field (HDF) is a snapshot of a tiny patch of sky in the constellation Ursa Major. It covers an area of just one 24-millionth of the whole sky. And yet this minute window reveals around 3,000 galaxies crowded together, giving astronomers a vital window into the past.

There had been predictions that the light emitted from such distant objects would be stretched out so much that they would appear as nothing more than faint smudges against the blackness. They could not have been more wrong. This image, made up of 342 separate exposures taken over more than 100 hours, showcased the power of Hubble. It revealed an incredible amount of detail and structure to galaxies that had never been seen before.

"A lot of astronomers were sceptical that we would learn a lot from simply pointing the telescope at a fairly arbitrary spot in the sky and taking long exposures," says Dr Henry Ferguson, a member of the original HDF team. However, the plethora of information that appeared convinced most that this was a good technique. As the telescope's capabilities were upgraded, projects such as the Hubble Ultra Deep Field continued where HDF left off.

Today, astronomers are finding galaxies from a time when the Universe was only 500 million years old. As a result, it has become possible to chart galaxy evolution directly, by measuring how properties such as size, shape and colour change over time. "The HDF became one of the major 'watering holes' for studying galaxy evolution, with deep observations spanning X-ray to radio wavelengths," continues Dr Ferguson. "It is one of the most important observations ever made with any telescope!"



Don't miss *25 Years Of The Hubble Space Telescope,* £7.99. Available to pre-order at buysubscriptions.com/hubble

Watch Chris Lintott and Maggie Aderin-Pocock discuss Hubble on *The Sky At Night,* 12 April

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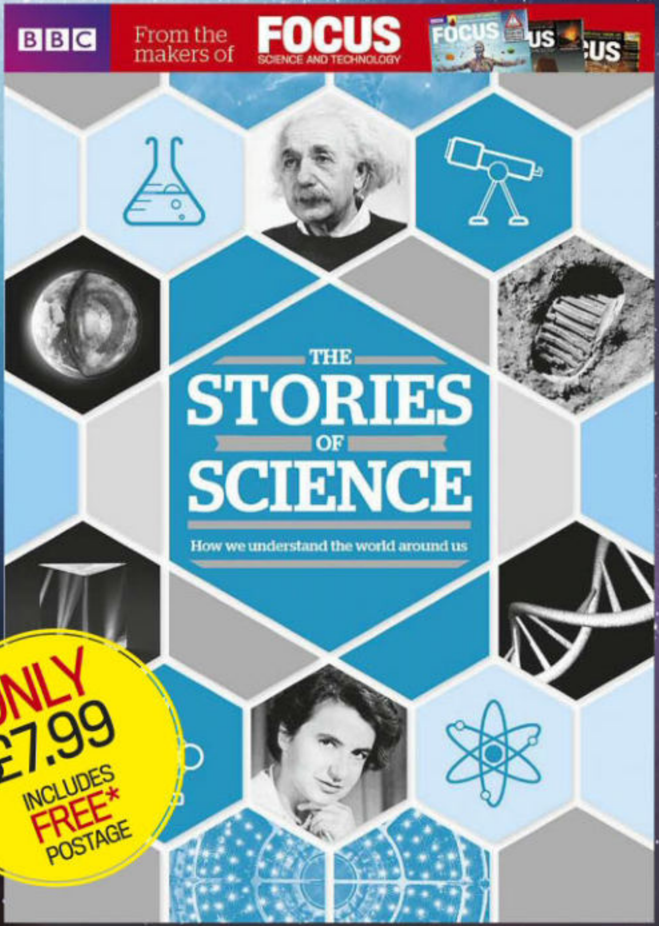

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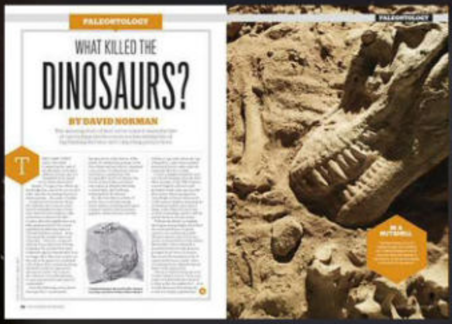

PALEONTOLOGY

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BY DAVID NORMAN

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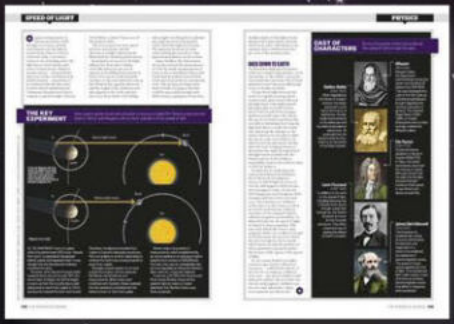

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MEET THE FIRST DIGITAL LIFE FORM

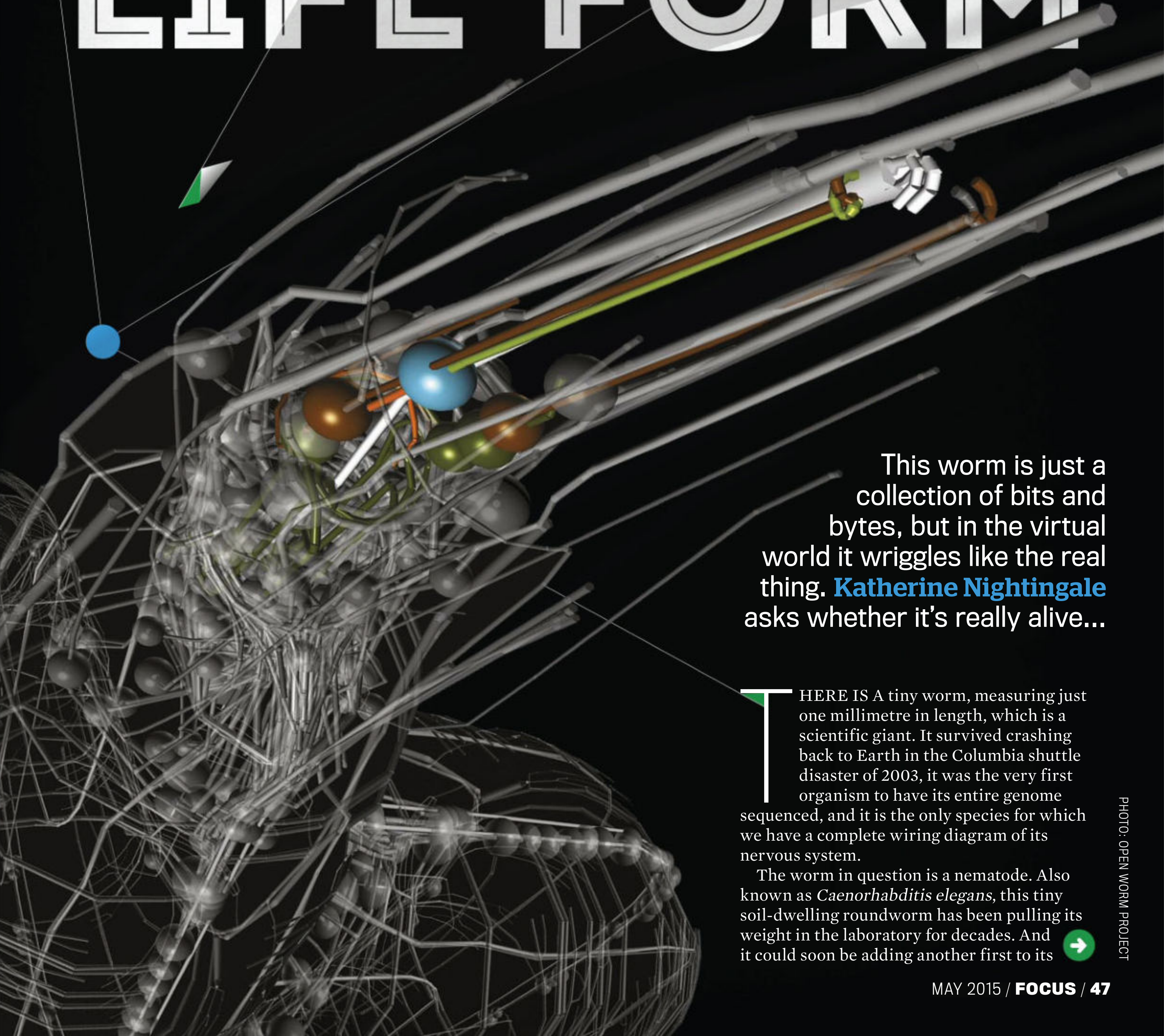


PHOTO: OPEN WORM PROJECT

This worm is just a collection of bits and bytes, but in the virtual world it wriggles like the real thing. **Katherine Nightingale** asks whether it's really alive...

THERE IS A tiny worm, measuring just one millimetre in length, which is a scientific giant. It survived crashing back to Earth in the Columbia shuttle disaster of 2003, it was the very first organism to have its entire genome sequenced, and it is the only species for which we have a complete wiring diagram of its nervous system.

The worm in question is a nematode. Also known as *Caenorhabditis elegans*, this tiny soil-dwelling roundworm has been pulling its weight in the laboratory for decades. And it could soon be adding another first to its list – it's well on the way to becoming the very first animal to be digitally recreated in a computer.

But why do we want or need digital worms? What can we learn from a worm that is made out of bits and bytes, and will these digital creatures be truly 'alive'?

C. elegans is a lab favourite because it is simple, consisting of just 959 cells. Of these, 302 are neurones (nerve cells). It is easy to keep and breed in petri dishes of agar. We know more about the little *C. elegans* nematode than any other lab animal, and it shares a surprising amount of its genetic code with human beings.

This makes it an ideal candidate for studying human genetics and disease, and it is a good place to start if you want to create a digital animal from scratch.

The virtual worm can be experimented on much more easily than a real worm, says Stephen Larson, one of the founding members of the OpenWorm project behind the initiative. According to Larson, who has a background in neuroscience and computer science, any worms produced will be 'editable', rather than finished products. There might even be scope to carry out experiments that aren't physically possible in the lab.

"The goal is that it's not just interesting, but it's helpful – you can ask hypothetical questions in the digital worm and then go and check in the real worm," he says.

> "YOU CAN ASK HYPOTHETICAL QUESTIONS IN THE DIGITAL WORM AND THEN GO AND CHECK IN THE REAL WORM"
>
> Stephen Larson, founding member and coordinator of the OpenWorm project

Stephen Larson wants to know how computers can help us to understand life

These roundworms were flown to the International Space Station to study muscle loss in a low-gravity environment

Scanning electron micrograph of the *Caenorhabditis elegans* roundworm. From tip to tail it measures just 1mm

BUILD A BEASTIE

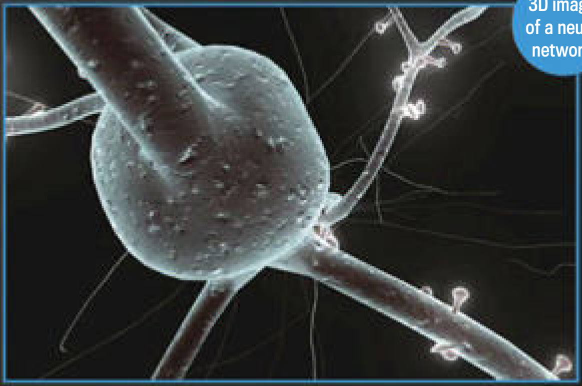
But it could also be a useful test of whether such a feat would be possible for other animals, or even humans. For example, a simulated human brain inside a computer would be helpful for studying various diseases. This is the aim of the field of artificial intelligence – the development of computer systems that can carry out tasks of which only human beings are normally capable. There are two ways that you could go about building a digital *C. elegans*. The first is to program a worm-like creature so that it moves like a worm and responds to certain stimuli the way a worm does. This is the way that artificial intelligence efforts usually work, aiming to reproduce human-like intelligence without also reproducing the brain's physiology.

But just recreating behaviour isn't the goal – that wouldn't be particularly useful for finding out how the real

PHOTO: OPEN WORM PROJECT, SCIENCE PHOTO LIBRARY X3, GETTY, HUMAN BRAIN PROJECT

ARTIFICIAL LIFE

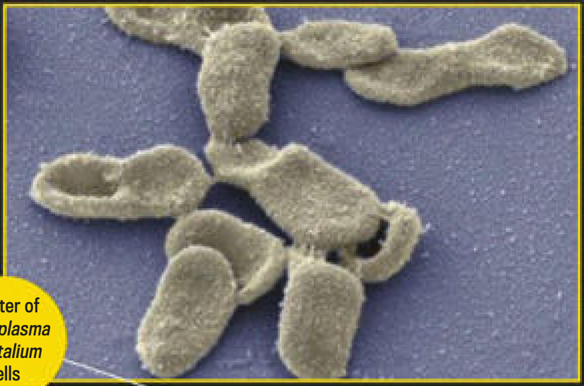
It's not just the nematode that's getting computerised - the digital tree of life has many different branches



3D image of a neural network

THE HUMAN BRAIN PROJECT

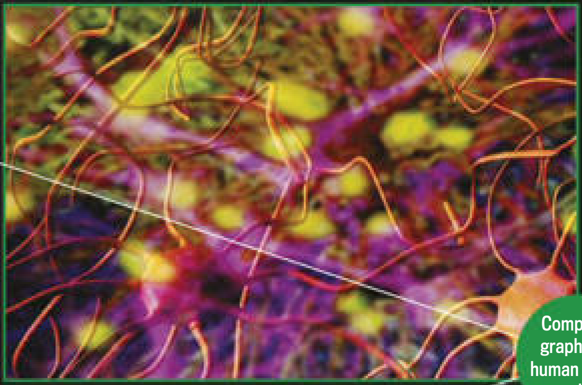
This 10-year project aims to simulate a human brain in a supercomputer. Backed with €1bn from the European Union, it involves 112 organisations in 24 countries in Europe and the rest of the world. But it has been criticised by some scientists for being premature and misdirected.



Cluster of *Mycoplasma genitalium* cells

A DETAILED CELL

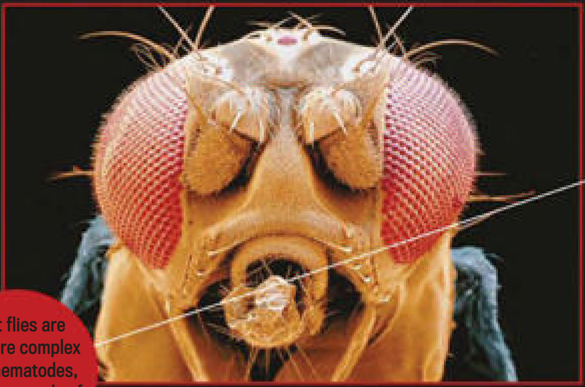
The laboratory of Professor Markus Covert at Stanford University in the US built the first digital model of an entire organism. The organism is a single-celled parasitic bacterium called *Mycoplasma genitalium*, but its tiny size didn't make it any easier to simulate - the researchers attempted to include all the cell's processes integrated together.



Computer graphic of human nerve cells

THE BRAIN INITIATIVE

The BRAIN (Brain Research through Advancing Innovative Neurotechnologies) Initiative was announced by the US Obama Administration in 2013. It aims to map the activity of every neurone (nerve cell) in the human brain. Inspired by the Human Genome Project, it is likely to cost billions of dollars over 10 years. It has also received criticism from researchers.



Fruit flies are far more complex than nematodes, with thousands of neurones

A FRUIT FLY'S BRAIN

NeuroKernel is a project aiming to reproduce the brain of the fruit fly (*Drosophila melanogaster*) in a computer. The fruit fly brain has up to 150,000 neurones, and is a common model for studying genetics. Like OpenWorm, NeuroKernel is open source.

worm actually works. OpenWorm is building a cell-for-cell replica of the worm, so we can start to understand how its behaviour emerges out of its physiology. So what do you need to build a worm in a computer?

WELL-CONNECTED

The *C. elegans* connectome has been around since the 1980s. This is a map of how all its neurones are wired up, although it has been improved upon since it was first assembled. The team has also used a three-dimensional body plan of the worm, which includes its muscles, nervous system and skin.

But just having a map isn't good enough – you need to know how the cells are behaving too. For this, the team has turned to the reams of scientific data on the functions of *C. elegans* cells and how they interact.

Larson and his colleagues – who are all volunteers – are spread throughout the world and keep costs low by meeting virtually online. The OpenWorm project, which began in 2011, is an example of 'open science' – they publish all their code on the internet for anyone to use, and conduct all of their meetings and discussions in public forums.

In this respect, it's a thoroughly modern project. It began with a tweet in 2011, and although OpenWorm receives no science funding in the traditional sense, it raised more than $120,000 on Kickstarter in 2014.

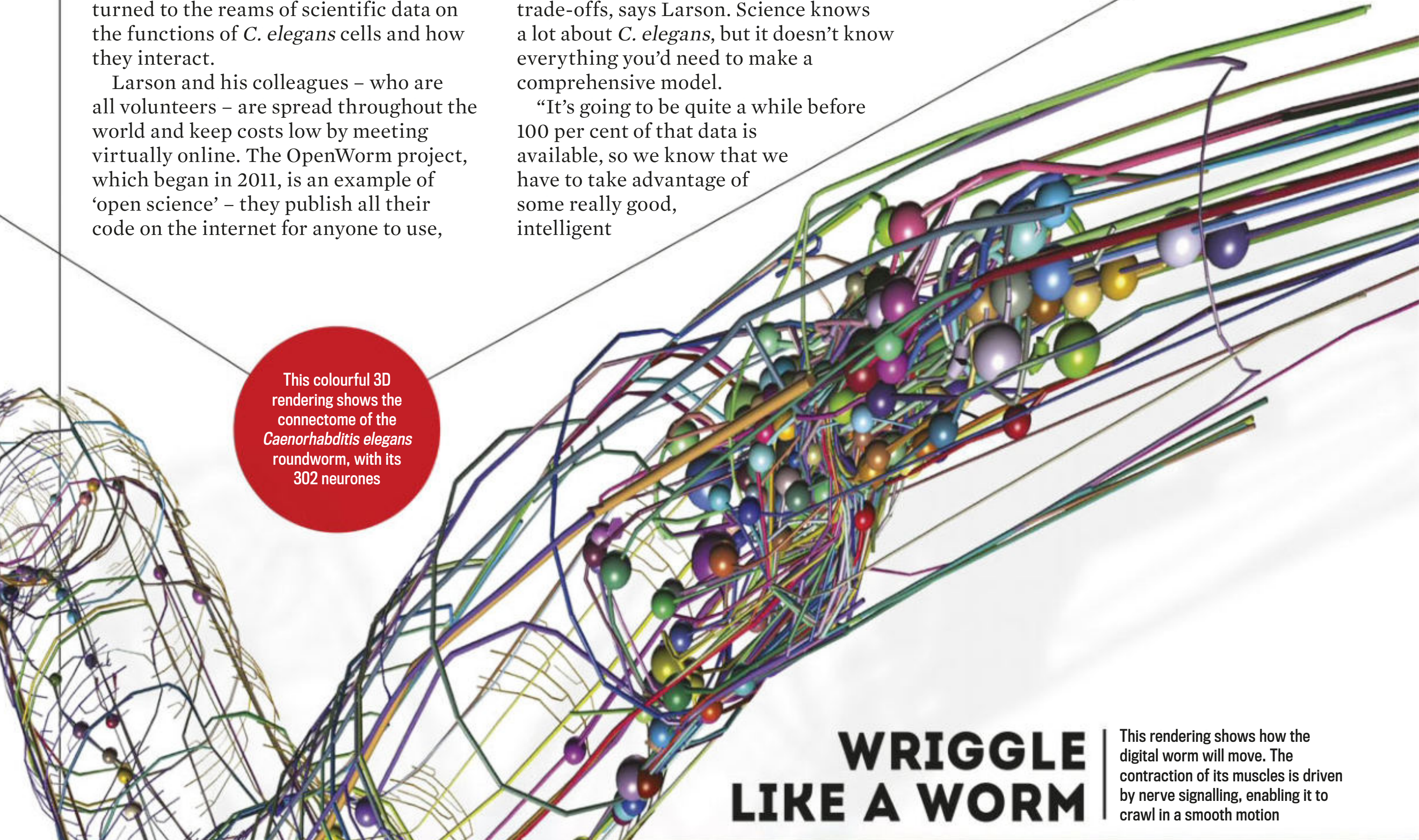
Larson can see many advantages to this way of working. "Everyone is really excited and passionate – if they weren't, they wouldn't be working on it," he states.

And it's lucky that they are excited, because a lot of work is required to simulate a worm in a computer. All of the models are simply an approximation of the thing they are trying to replicate. The question is how closely a model has to resemble the original, and how much detail you go into. It's a case of making trade-offs, says Larson. Science knows a lot about *C. elegans*, but it doesn't know everything you'd need to make a comprehensive model.

"It's going to be quite a while before 100 per cent of that data is available, so we know that we have to take advantage of some really good, intelligent guesses about certain aspects of the model. We've chosen this animal because we'll have to make the fewest guesses with it than with anything else," Larson says.

The team members aren't drilling down to the level of what's going on inside cells. That would require vast amounts of computing power, and it probably isn't necessarily going to get the digital worm behaving like a real one. Instead, they're starting with locomotion. So far, they've got a complete model of the nervous system, and have created a model of the worm's 95 muscles. They've also produced a virtual worm body that crawls in a digital simulated environment.

"We're working to plug the nervous



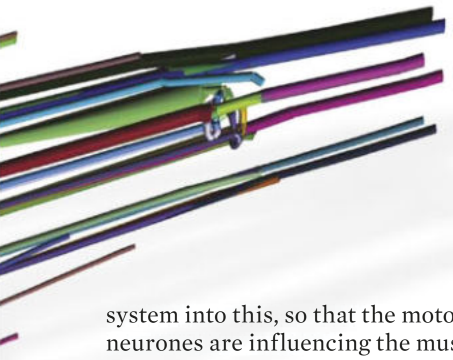
This colourful 3D rendering shows the connectome of the *Caenorhabditis elegans* roundworm, with its 302 neurones

WRIGGLE LIKE A WORM

This rendering shows how the digital worm will move. The contraction of its muscles is driven by nerve signalling, enabling it to crawl in a smooth motion

PHOTO: OPEN WORM PROJECT X3

> **“WE’VE CHOSEN THIS ANIMAL BECAUSE WE’LL HAVE TO MAKE THE FEWEST GUESSES”**
>
> Stephen Larson, founding member and coordinator of the OpenWorm project



Stephen Larson (above) says, “Our interest in smarter AI is to learn principles of modelling neurones that will give us insight into human intelligence”

system into this, so that the motor neurones are influencing the muscles. And we have the integration environment that can display the results of a worm simulation on the web,” says Larson. The integration environment is called Geppetto, and the goal is for people to use it to play with the worm simulation via their web browser.

Starting with the nervous system and muscles means that easily visible behaviour is simulated, which can then be compared with how real *C. elegans* worms move in the lab. This lets the team see how close the model is to the real thing.

One day, the team hopes to include processes like digestion and reproduction. But for now, it’s all about how the worm moves through its digital agar.

So if we can do it for a worm, can we do it for other animals as well? Murray Shanahan, Professor of Cognitive Robotics at Imperial College London, thinks it’s possible. The main obstacle will be getting enough data about, say, the 75 million neurones in a mouse brain to have enough information to build a model. We don’t have a mouse connectome yet, and we don’t understand the behaviour of many of the neurones.

But, explains Shanahan, there has been a huge amount of progress in studying brain activity in mice at that neurone-level scale in recent years. “I’d be surprised if we couldn’t [simulate a mouse brain] in 20 years and I wouldn’t be surprised if we could do it in 10,” he says.

LAWS OF LIFE

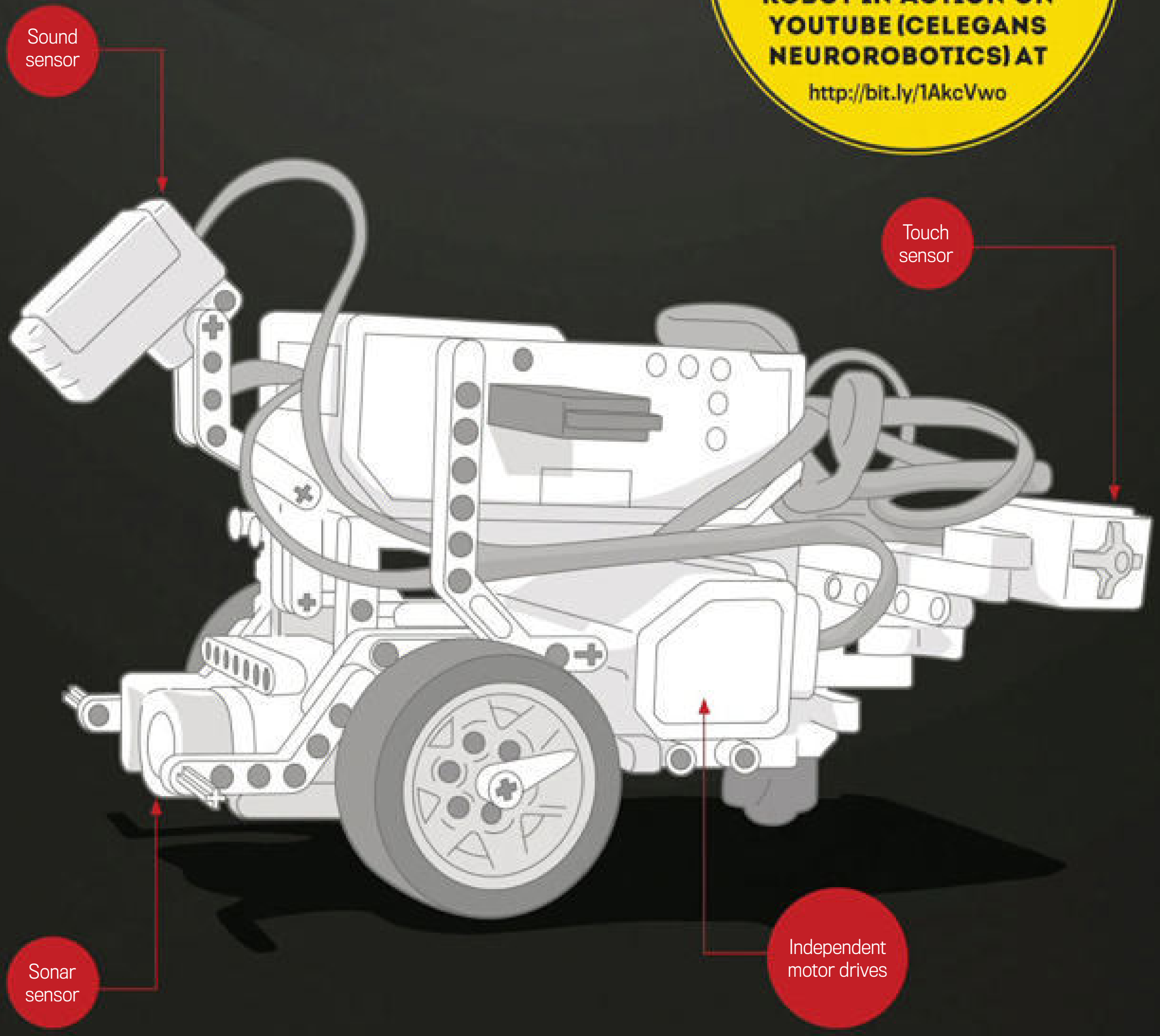
So, if it looks like a worm, crawls like a worm and responds like a worm, then is it a worm? Even if the project manages to simulate all the components of the worm, and it is reproducing, feeding and moving around in a digital version of its agar, it is still not alive, says Alan Winfield, Professor of Electronic Engineering at the University of the West of England and a Bristol Robotics Laboratory researcher.

“There are plenty of video games in which the virtual creatures also arguably have those characteristics and we never think of those as alive. They are simulations – a simulation of a thing is not a thing,” explains Winfield.

LEGO WORM

What happens when you combine a worm's connectome with a children's toy? You get a pretty cool robot...

WATCH THE WORM ROBOT IN ACTION ON YOUTUBE (CELEGANS NEUROROBOTICS) AT
http://bit.ly/1AkcVwo



IN 2014, RESEARCHER Timothy Busbice put a neural network into a Lego robot, which was based on the *Caenorhabditis elegans* worm's connectome. The robot's two wheels are controlled by 95 cells to replicate the muscles of the roundworm. The worm's sensory organs, which would normally respond to smells and tastes, are instead wired up to respond to sound, while its touch-sensitive 'nose' has been replaced with sonar. In one online video, the robot is seen approaching a wall and then backing away. Rather than this being a behaviour that has been programmed into the robot, it's thought to be an outcome of the worm's neural network.

OpenWorm founder Stephen Larson has yet to 'look under the hood' of the Lego robot with his team, but he says: "We are excited about people being creative and we'd love to see a lot more people plugging ever-evolving versions of the model nervous system into robots."

PHOTO: TIMOTHY BUSBICE, ALLEN INSTITUTE FOR BRAIN SCIENCE, ISTOCK

> **"PEOPLE MIGHT HAVE A STRONGER REACTION TO SOMETHING THAT'S IN A PHYSICAL BODY"**
>
> Alan Winfield, University of the West of England

Pictured is a top-down view of the connections between neurones (nerve cells) in the brain of a mouse

For Shanahan, the more interesting question is whether a digital worm would be conscious. Few people would say that a real *C. elegans* is conscious – it's far too simple to experience its surroundings or suffer – but if the same were to be done for a mammal such as a mouse, you probably would class it as conscious, he says.

"If a simulation of a mouse's brain was embodied in a virtual body, or particularly in a real body, we might be tempted to say that it was conscious," says Shanahan. "If the kinds of signals that come from sensory neurones and go to motor neurones are pretty much the same, and it exhibits the kind of behaviour you would expect, I would find it very difficult to see how you could justify saying that it wasn't conscious in so far as a real mouse is conscious."

Winfield is keen that we start to have discussions surrounding the ethics of creating such digital animals. He sees little difference between a simulated mouse in a computer and one that has been embodied outside a computer. "People might have a stronger reaction to something that's in a physical body, especially if it somehow mimics a real animal, but actually there's no real difference in terms of concern over whether it experiences suffering."

The OpenWorm team is concentrating on making a useful model in a computer for scientists, and don't intend to make a worm – or a mouse – with a real-world body any time soon. But their efforts to recreate a tiny worm in a computer are getting to the heart of some of the biggest questions in artificial intelligence today. ■

KATHERINE NIGHTINGALE is a science writer at the Medical Research Council

BBC WORLD SERVICE

Listen to *The Inquiry* on whether we should fear AI at http://bbc.in/1waGSvN

CAN WE MAKE A REAL TRICORDER?

A *Star Trek*-style scanner would eliminate routine trips to the GP, allowing any of us to claim: "Dammit, Jim, I'm a doctor!" **Lilian Anekwe** reveals the future of healthcare

THE CREW OF the USS Enterprise became ill with alarming regularity. From Andorian shingles to Zanthi fever, all manner of intergalactic diseases were waiting to pounce on the crew whenever they set foot on alien planets. Mercifully, the ship's doctor always had a tricorder to hand, which could diagnose all manner of alien ailments in seconds. A quick once over was all it took to find out if a patient had a case of choriocytosis (a deadly disease for Vulcans) or just a common cold. There were no lab tests, no needles and no waiting. It's an idea that seemed more science fantasy than fiction, but that might be about to change.

Last year, a new $10m (£6.5m) X Prize was launched that challenged inventors to build a real-life tricorder. The X Prize's philanthropic backers are offering to fund a team that can design a device weighing less than 2.3kg that is

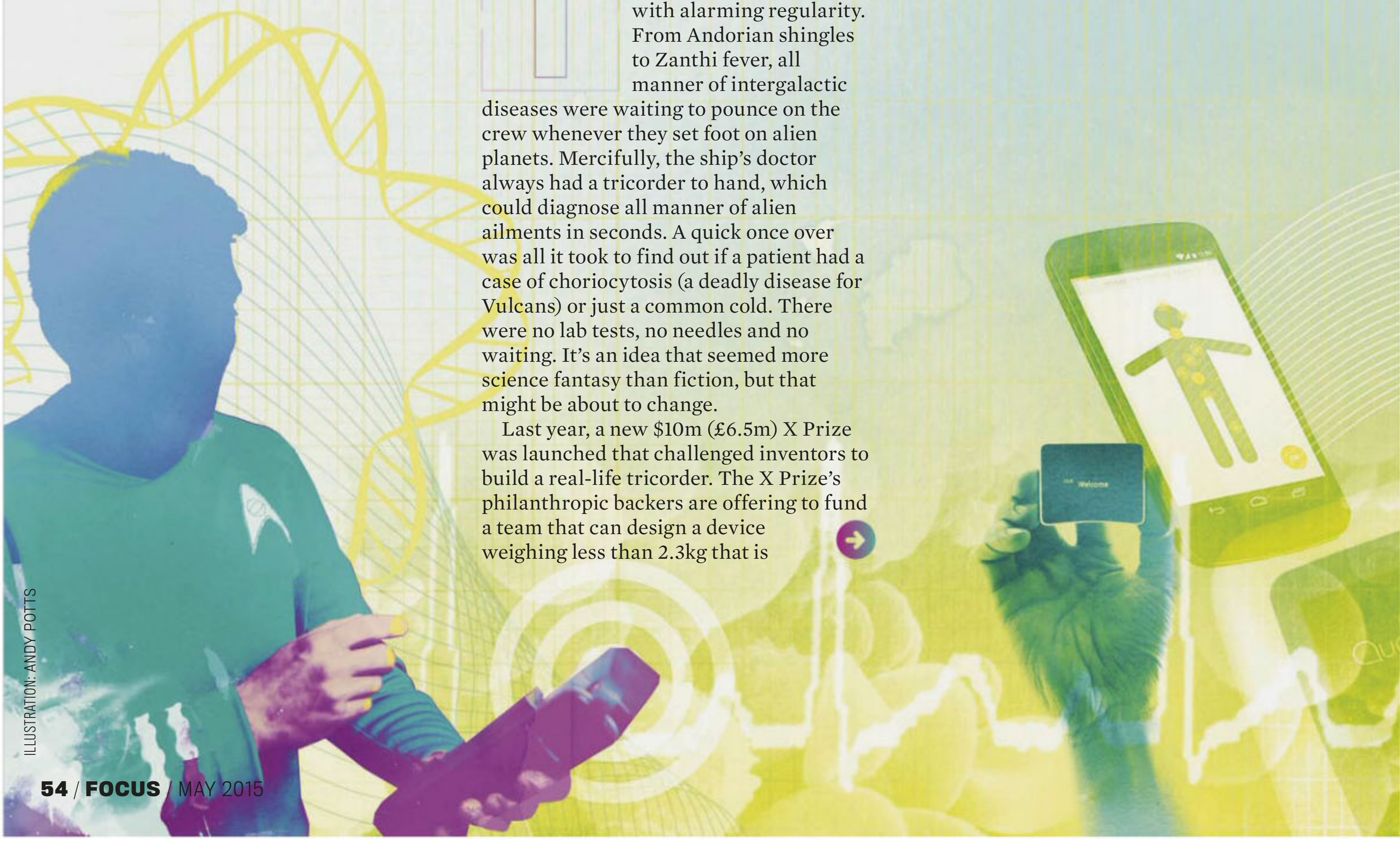


ILLUSTRATION: ANDY POTTS

BLOOD PRESSURE 120
80
99°
CIRCULATION
86BPM
QuantuMDx
Unlock

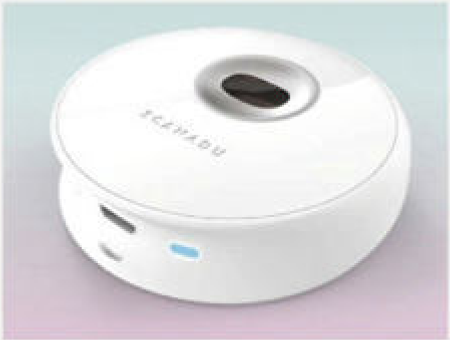
"capable of capturing key health metrics... to accurately diagnose 16 health conditions [and] five real-time health vital signs: blood pressure, heart rate, oxygen saturation, respiratory rate and temperature." Okay, so it might not be smart enough to take to an alien planet any time soon, but could it launch a revolution in personal medicine?

The X Prize's 10 finalists were announced in September 2014, and one of the front-runners and favourites is Scanadu, a medical technology company based at the NASA Ames Research Center in southern California. The group is led by Dr Walter de Brouwer, a Belgian inventor who says he wants to build a 'Google for health'. This would be a global shared 'brain' of digital health data that inventors, researchers, doctors and the public could all benefit from.

The device, the Scanadu Scout, is a vital signs monitor that takes your readings when you hold it to your left temple. In seconds, it measures your heart rate, temperature, oxygen saturation and blood pressure. It sends the data to your phone via a Bluetooth connection – allowing you to view and track your vitals wherever you are. If you add the Scanaflo, you can pee on a stick to test your levels of glucose, protein, leukocytes, nitrites and more.

> "There hasn't been innovation in tracking your health at home since the thermometer"

Right and below: *Star Trek*'s Dr McCoy and the show's vision of a medical scanner – the tricorder



Bottom right: Unlike its *Star Trek* equivalent, the Scanadu Scout has no display, instead sending data to a smartphone

POWER TO THE PEOPLE

This concept is long overdue, de Brouwer says. "Shockingly, there hasn't been innovation in tracking your health at home since the thermometer."

Being able to wave a device at someone and get potentially lifesaving information about their health could drastically shift the dynamic between medics and patients, and make amateur doctors of us all. You may be used to giving your symptoms a quick Google before visiting the doc, but a tricorder-style device could refine your knowledge and arm you with richer and more accurate data. "My goal is to make this the last generation to know so little about their health," de Brouwer states. And it seems the demand is definitely out there, as the Scanadu Scout raised more than $1.6m (£1m) in funding during a 2013 crowdsourcing campaign.

Away from the prestige of the X Prize, there are other research companies quietly working on modern tricorders. In the UK, the biotech company QuantuMDx makes diagnostic devices that the company says could play a role in addressing humanitarian health challenges, such as malaria, cancer and drug-resistant tuberculosis.

The jewel in QuantuMDx's crown is the Q-POC, a 'handheld laboratory' that analyses DNA and delivers the results of a battery of diagnostic tests in a few minutes. The device reads and sequences DNA and converts it into binary code using a tiny computer chip. The sequence is then translated into a simple message for the user to read and interpret what the DNA analysis actually means. You simply place a sample into the

PHOTO: QUANTUMDX, CORBIS

HOW DOES THE Q-POC WORK?

THE FIRST GENERATION of the Q-POC will be built to detect malaria in blood, but the team is also working on other versions that could diagnose tuberculosis from spit. They are even considering a device that would be able to detect cancer in biopsies.

1. THE SAMPLE

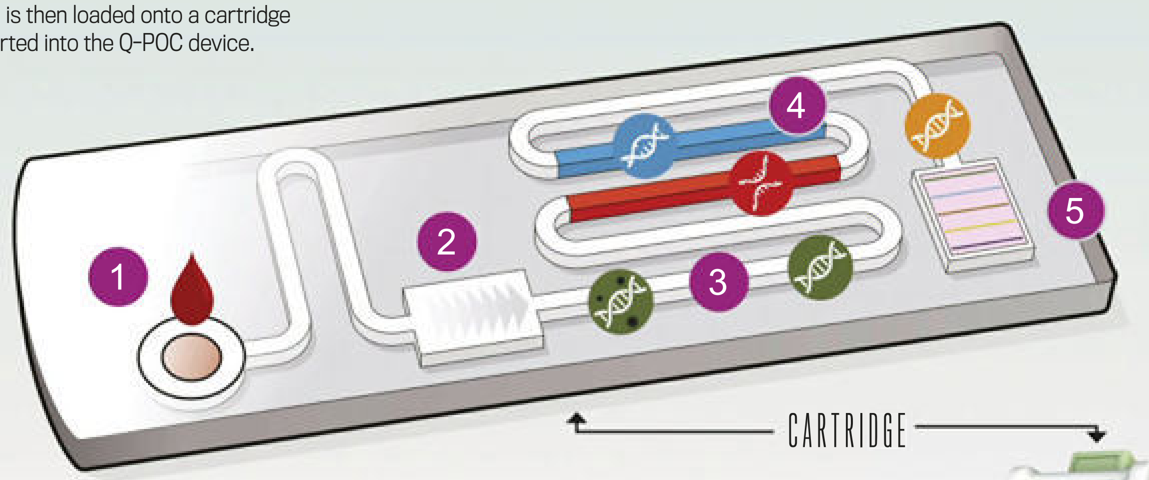
A drop of blood is taken from the finger of a patient. This is then loaded onto a cartridge and inserted into the Q-POC device.

2. BREAKDOWN

The blood is then broken down in a process called lysis. For this to take place, the sample is channeled into a chamber containing a small motor – the kind that makes your smartphone vibrate – that has a blade attached. This miniature blender breaks down the cells into a soup (called a lysate) containing DNA and the rest of the molecular junk, such as cell membranes and proteins.

3. CAPTURE

The DNA needs to be separated from all this molecular junk, so a special molecular filter is added. This gets rid of the all the rubbish, leaving only the genetic material behind. The traditional lab approach involves 'rinsing' the junk away from the DNA, which requires clean water and takes one to two hours. The Q-POC can do it in three minutes.

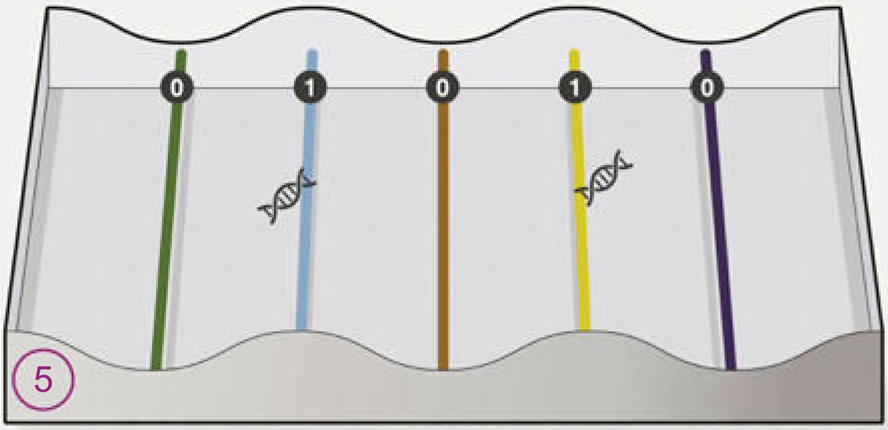


4. AMPLIFICATION

The DNA moves into a channel where it is heated and cooled. This separates the two strands of the DNA helix, allowing a special enzyme to copy the DNA. There could be lots of different strands of DNA from pathogens inside the sample; the enzyme is selected to only reproduce the DNA sequence relating to one disease, in this case malaria.

5. ANALYSIS

This solution is passed over a series of nanowires embedded onto a chip. The wires are so tiny that 100,000 could be squeezed onto a human hair. These wires act as biosensors. Malarial DNA binds to the wire when it passes over it, causing a change in resistance. This tells the Q-POC that malaria is present. The whole process takes 15 minutes.



THE FUTURE

Without Q-POC, a sample would need to be sent to a lab, wasting days at a time. The traditional process takes a lab technician an entire day to complete. The goal is for the Q-POC to be able to test specific symptoms. If a patient reported a fever, for example, a cartridge could confirm that the pathogens responsible for inducing fever were present. The company also hopes to charge the Q-POC with solar-powered battery packs so testing can be done even if electricity isn't available. The system doesn't require water, making it perfect for helping deliver treatment to developing countries.

cartridge, insert the cartridge into the device and press 'Go'. In around 15 minutes your results are presented on the screen.

HEALTH HELPER

"The Q-POC does the work of four different machines in one handheld device and generates an output that can be used for diagnosis," explains QuantuMDx's chief executive Elaine Warburton. "It might sound like the sort of thing that you see on *CSI Miami*, but we took that technology, then re-engineered and miniaturised it into a cassette the size of a credit card."

The Q-POC can also be used to track outbreaks of infectious diseases, by sending up-to-the-second test results via GPS and mobile networks. In developing countries where resources and healthcare professionals are scarce, the impact of this kind of device could be profound.

The makers of both devices say that the aim is to eventually make their tricorders available direct to consumers. But both still need to be tested in clinical trials and approved for accuracy and safety by the US Food and Drugs Administration in the case of the Scanadu Scout, and by the UK CE marking body for the Q-POC before its slated soft launch in late 2016.

De Brouwer is convinced that giving everyone this level of information about their health is an empowering force for good. "Having that knowledge empowers you to have more informed conversations and more productive visits with your doctor," de Brouwer states.

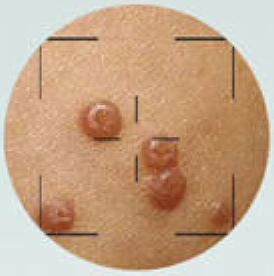
And Warburton agrees with him. "We're working with clinicians on the nature of the output – the actual results the Q-POC generates on-screen. They need to be accurate, of course, but also presented in a way that is most useful to the user, be that a pathologist, a healthcare professional or Joe Public."

But there's scepticism from the medical community about whether the tricorder could ever be useful. Dr David Warriner, a member of the Royal College of General Practitioners' overdiagnosis group (and a *Star Trek* viewer in his youth), says the tricorder pretenders are some way off being diagnostic devices in the clinical sense. Warriner argues that when it comes to our health, more information is not always better. By giving everyone access to their health data out of context and without any medical counselling, it could mean that doctors are left to deal with the fallout from these devices when worried patients incorrectly interpret the

PATIENT, HEAL THYSELF

Can't wait for your tricorder? These high-tech health helpers are available now

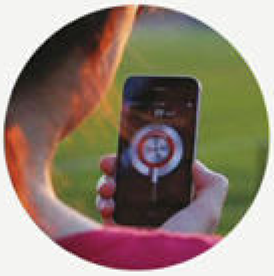
23andMe
23andMe's test analyses the DNA in saliva and tells you if you're at low, typical or high risk of diseases such as Alzheimer's and Parkinson's. It also tells you if you have genes that are linked to inherited conditions like cystic fibrosis.



First Derm
If you've got a skin complaint that you're concerned about, simply snap a picture, fill in a form and send it off to First Derm via the website or the iPhone app. Within 24 hours a dermatologist will let you know what to do next.

Cloud DX Pulsewave
The Pulsewave is worn as a wrist cuff so you can check your heart rate and blood pressure, and test for heart anomalies. The data is stored by Cloud DX and can be accessed and tracked, allowing you to look for trends and patterns.

Peek Vision
The Peek Vision app and adapter turns your phone into an eye examination kit. It can check visual acuity, scan the retina and identify cataracts. It gives quick and easy access to the tools needed to prevent blindness.



Cardiio
The Cardiio app transforms your iPhone or iPad into a heart rate monitor. When your heart beats, more blood rushes to your face. Cardiio's software is able to detect these tiny changes when your device is held in front of you.

Cellscope Oto Home
The Oto Home device is inserted into the ear, and the app guides you through the process of taking an examination. It'll offer a doctor's response in just two hours. At the moment, Oto Home is only available in California, but may be rolled out further.

PHOTO: KOBAL COLLECTION, GETTY

Below: X Prize finalist the Dynamical Biomarkers Group created this tricorder concept with accessories that can test blood, breath and urine

Above: Elaine Warburton at Downing Street with an early Q-POC prototype

Right: The Scanadu Scout is held against the head to take health readings

results and rush to their GPs for reassurance. Nevertheless, de Brouwer insists that being aware of your health data can alleviate anxiety.

While Warriner agrees that the devices will empower patients, he cautions that one-off measurements are seldom of use. “It is patterns, which emerge over time, that indicate the presence of significant pathology. Simply measuring and recording the data is not enough,” he explains. “If a test is negative, then there is a danger the patient will be falsely reassured and will then smoke, drink and eat to their heart’s discontent. Or if it is positive, then a patient may live the rest of their life with the Sword of Damocles hanging over them.”

Despite the doubters, de Brouwer is convinced the potential for the Scanadu Scout is limitless. He states that consumers want to be more informed, so the potential market is huge. This is backed up by the diverse group of prospective customers that Warburton says is already interested in the Q-POC. These include Western governments interested in detecting biological weapons, forensic police units wanting them for crime scene investigations, and archaeologists identifying fossil species.

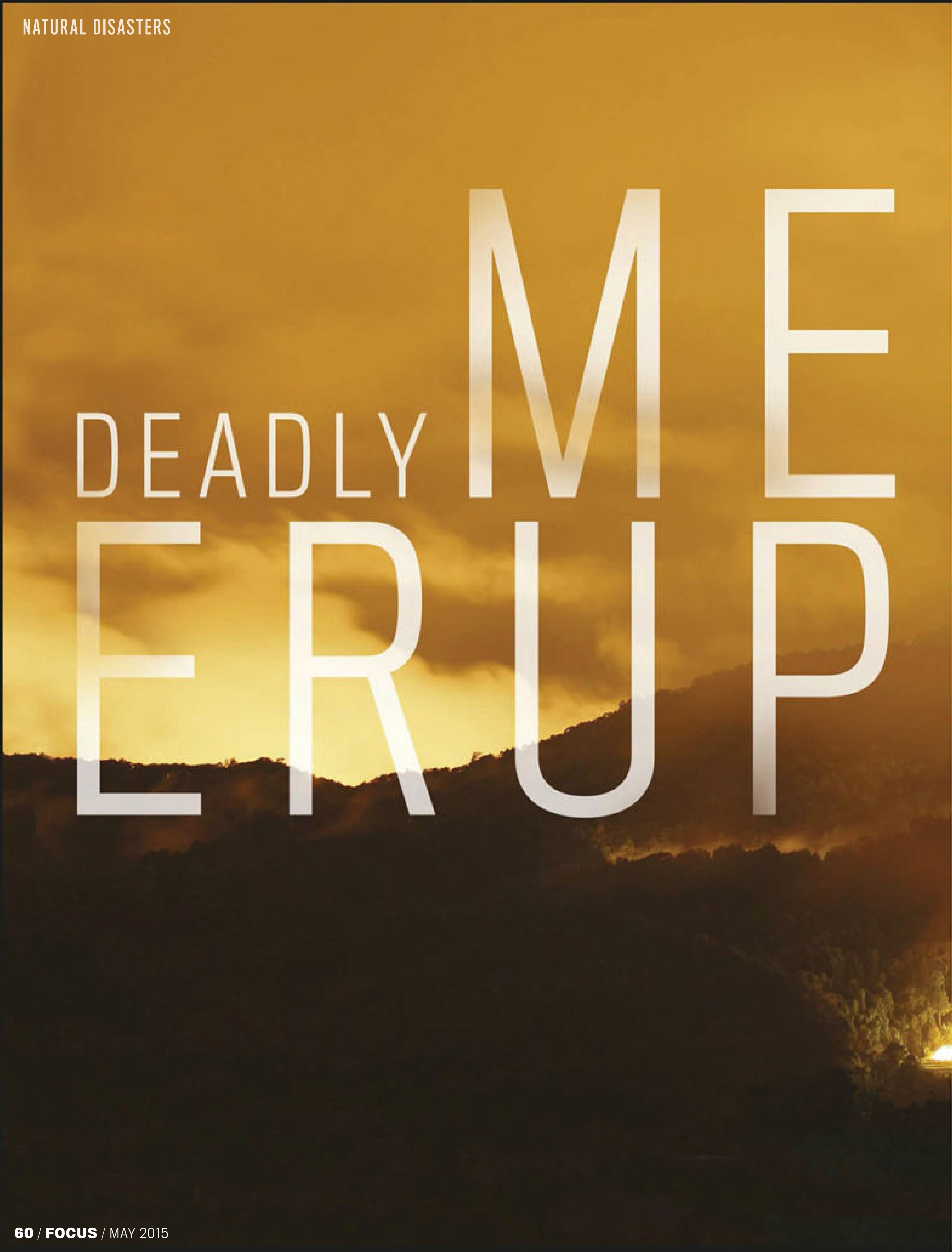
But it’s in the medical field that a tricorder could really create a fundamental change in how we think about our health. Checking your symptoms online could become a vastly different experience, and it could soon be the norm for your GP to take a look at your symptoms with their smartphone. Dr McCoy would be proud. ■

> **“It is patterns, which emerge over time, that indicate the presence of significant pathology”**

LILIAN ANEKWE is a medical journalist and editor at *Pharmafocus*

BBC NEWS

To watch an episode of *Click* that covers tricorder devices, visit **http://bbc.in/1AgALwx**



DEADLY ME
ERUP

GATION

April 2015 marks 200 years since Tambora exploded, searing into history as the most powerful volcanic eruption since records began. **Bill McGuire** asks if it could happen again...

THE TEMPERATURE IS stifling, sucking the sweat from your body. Everything is utterly black. It is impossible to see your hand in front of your face. Worst of all is the blizzard of ash, falling so quickly that it clogs every orifice. You try desperately to suck in the scorching air, but the slimy concoction of ash and saliva that fouls your mouth and throat acts as a barrier. You are suffocating. It gets even hotter. A wave of blistering heat assaults your body, crisping your skin and bringing unimaginable agony. Your last act is to open your mouth to scream, but no sound emerges. Instead, you inhale super-heated gas that shreds your windpipe and destroys your lungs.

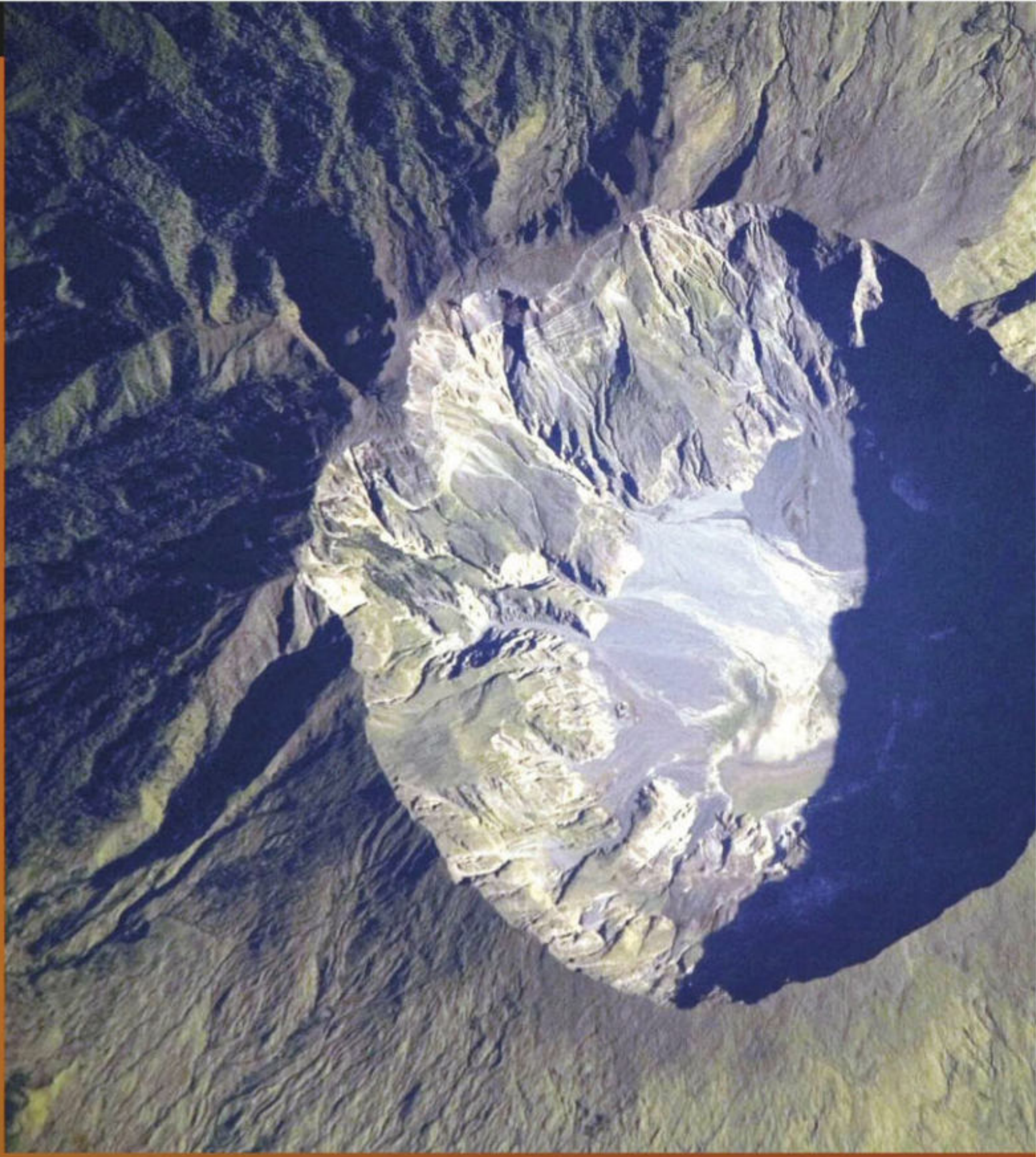
Death by volcano is not pleasant, as 12,000 inhabitants of the Indonesian island of Sumbawa discovered exactly 200 years ago. In April 1815, the island's Tambora volcano tore itself apart in the largest known eruption of the historical period, and one of the biggest since the Ice Age. But what happened in the weeks and months following the eruption, and will we ever be threatened by such an event in the future?

In many ways, those that succumbed to the deluge of ash and the tempests of boiling gases were the lucky ones. During the months that followed, five times as many people lost their lives on Sumbawa and neighbouring islands to the combined onslaught of famine and disease. And the lethal consequences did not end there; the huge volume of sulphur gases injected into the stratosphere caused climate mayhem half a world away.

As Tambora is secreted away on an obscure island in the Indonesian archipelago, the eruption might have gone unnoticed in Europe had it not been for a combination of fortuitous political circumstances. Having ousted the incumbent Dutch forces from the island of Java in 1811, a certain Thomas Stamford (later Sir Stamford) Bingley Raffles was installed by the British as Lieutenant Governor of the island. Famed today for establishing the city-state of Singapore and for the iconic hotel there that bears his name, Raffles also has the gratitude of today's volcanologists for the contemporary written accounts he provided of the Tambora blast.

As one of 78 active volcanoes in the world's most volcanically lively region, Tambora must have been a pretty impressive peak, with an estimated height of up to 4,300m. It had erupted just once in the previous five millennia, which undoubtedly convinced the local inhabitants that the volcano was long-extinct and presented no threat. It is possible that they did not even know the mountain was a volcano.

The first evidence that this optimistic assessment was way off the mark came in the spring of 1812, when the first rumblings began to make the local population nervous. Minor steam and



Left: Tambora's caldera is about 6km in diameter and up to 700m deep

TIMELINE

How it happened

1812

The first rumblings of the Tambora volcano for more than 1,000 years are followed by small detonations of steam and ash. Locals start to worry.

5 April 1815

The first major explosion lasts for two hours and sends ash to a height of 33km. The loud booms are misinterpreted in Java as cannon fire.

10 April 1815

A second blast launches the climactic phase of the eruption, which removes the top 500m or so of the volcano. Pyroclastic flows annihilate communities.

July 1815

The explosions end, leaving behind a 6km-wide caldera. About 12,000 are dead and a blasted landscape is buried beneath huge amounts of ash.

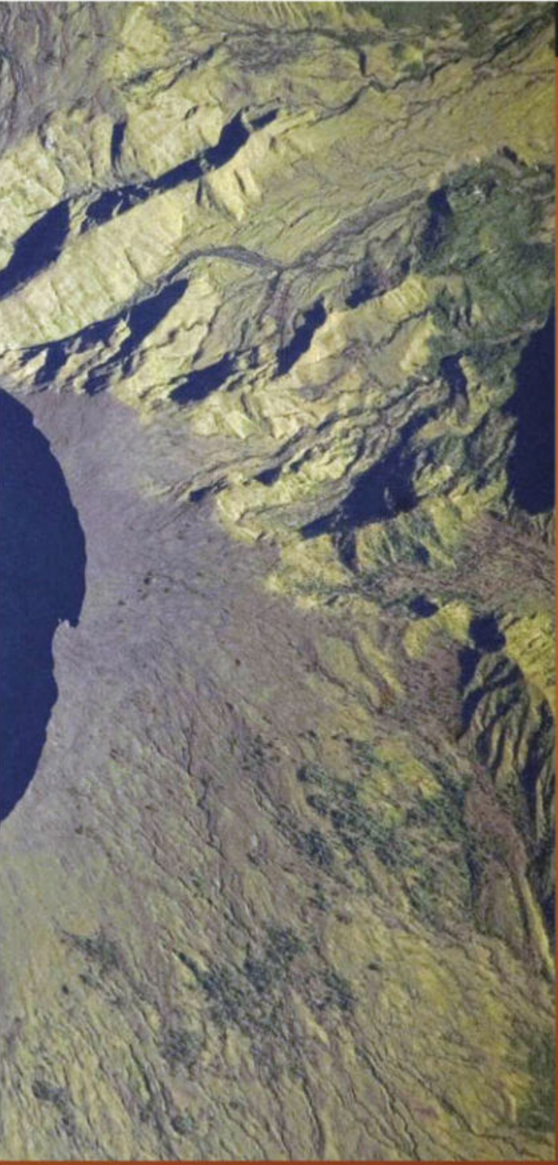
Months after

The destruction of crops and the burial of agricultural land brings famine that takes an estimated 60,000 lives on Sumbawa and neighbouring islands.

Summer 1816

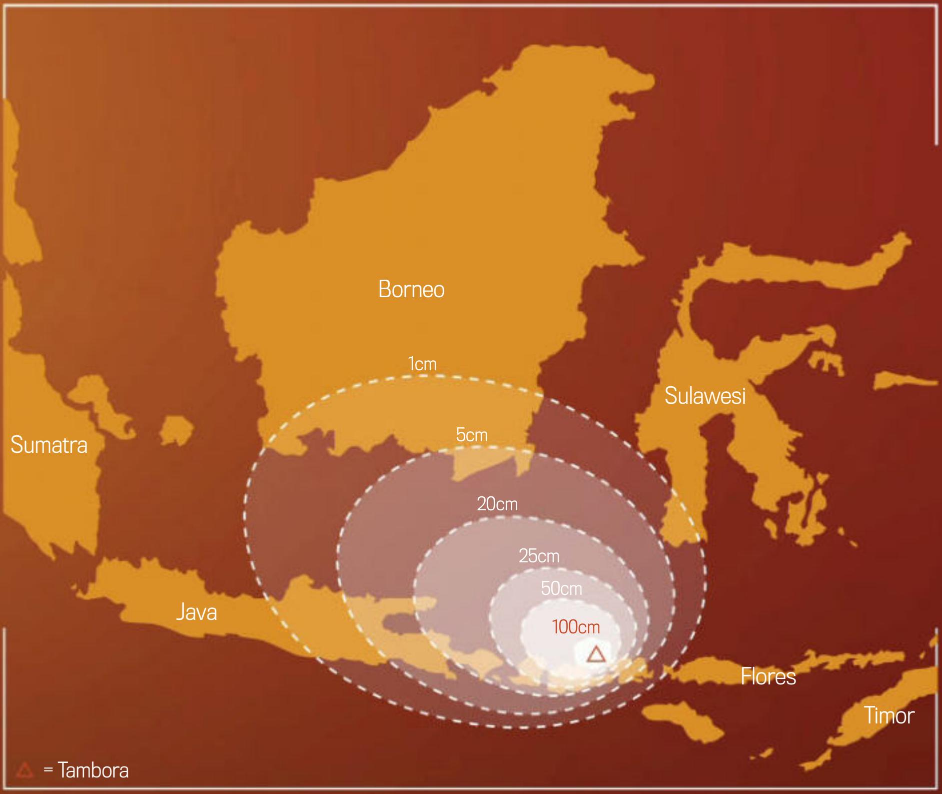
Unseasonably bitter weather wrecks harvests across the eastern United States and Europe. This brings bread riots, famine and disease.

PHOTO: NASA, RIK STOETMAN, PRESS ASSOCIATION



Left: Tambora measures about 60km in diameter at sea level, forming the Sanggar peninsula

Below: Depth of ash that fell on Sumbawa and neighbouring islands when Tambora erupted



Skeletal human remains excavated from a buried Sumbawa village

> **"Starvation and disease were rampant, eventually taking the lives of an estimated 60,000"**

ash explosions followed, but it was three years until things really started to get serious. The first titanic explosion occurred on 5 April 1815, the sound of which Raffles reports as carrying across to Java, where it spawned rumours of fighting and invasion. Following a short respite, a second colossal explosion five days later heralded the start of the climactic phase of the eruption, which seems to have lasted for three or four days. A gigantic, 45km-high column of ash reached to the edge of space, while hurricane blasts of scalding gas and hot ash scoured the surrounding land of all life. A powerful tsunami, spawned by the huge volumes of ash and debris flowing into the sea, buffeted the neighbouring coasts. When the ash-laden skies cleared weeks later, it was to reveal a decapitated volcano; its towering peak replaced by a hole measuring 6km across. The next few months were a living hell for survivors, whose homes and crops were buried beneath thick layers of ash. Disease and starvation were rampant, eventually taking the lives of an estimated 60,000 men, women and children.

BLAST FURNACE

In total, the eruption blasted out a staggering 50 cubic kilometres of ash and debris – around five times that ejected by the more famous Krakatoa eruption, nearly seven decades later. More than 20cm of ash fell in eastern Java, while even in Borneo, 500km to the north, ash was 5cm deep. Enormous rafts of pumice, some an astonishing 5km long, clogged the

A coil of rope lies within the remains of a collapsed building on the island of Sumbawa

Above: Eyjafjallajökull in Iceland caused chaos to European flights when it erupted in 2010

Left: JMW Turner's paintings, such as *Chichester Canal*, celebrate the orange-tinged sunsets that were seen following Tambora's eruption

surrounding ocean, hindering shipping in the region for three years after the eruption. The detonations during the climactic phase were felt over an even wider area, shaking buildings across Java and heard as far away as Trumon in north Sumatra, 2,600km from the volcano.

While the statistics of the Tambora eruption are impressive, the event is best known for its wide-ranging impact on the climate. The enormous volumes of ash settled out of the atmosphere in a matter of weeks. The 200 million tonnes of tiny sulphate particles, injected into the stratosphere, however, hung around for much longer, forming a so-called aerosol veil across the planet.

THE BIG CHILL

This veil proved very effective at blocking incoming sunlight, causing temperatures to plunge and inflicting an unseasonable chill upon the northern hemisphere. Earmarked in the historical record as 'the year without a summer', 1816 saw snow in New York state in June and unprecedented summer frosts wiping out crops across the eastern states. In Europe, the summer was the second coldest of the past six centuries, bringing widespread crop failures. The bread riots, starvation and disease that followed have been described as marking the last great subsistence crisis in the western world, taking – in Ireland alone – as many as 44,000 lives. Tambora's remote legacy also had some surprising cultural consequences that remain with us today. The brilliant, sulphurous sunsets that followed the eruption have been held up by some as providing inspiration for the increasingly flamboyant skies of some of JMW Turner's post-1814 works. Similarly, the weather of 1816 is charged with supplying the brooding backdrop that – during a 'wet and ungenial' summer spent at the Villa Diodati on Lake Geneva – inspired Mary Shelley to write *Frankenstein* and prompted Lord Byron to compose his poem, *Darkness*.

Now, 200 years on, we await the next Tambora with some trepidation. Volcanic blasts on this scale seem to happen, on average, a few times every millennium. The probability of another one coming along in the next 50 years is maybe 10 per cent, or even higher. Based

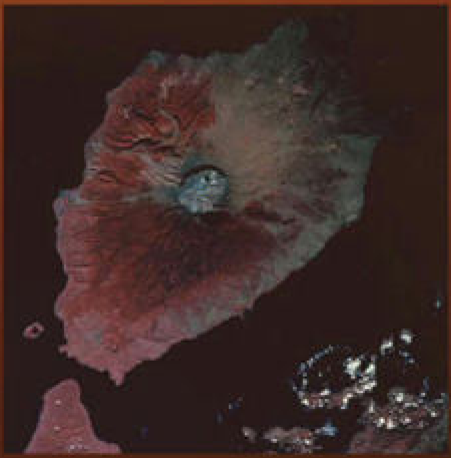
PHOTO: RIK STOETMAN, PRESS ASSOCIATION, GETTY, NASA, ALAMY

THE NEXT TAMBORA?

Volcanologists can pinpoint when an eruption will take place, but many volcanoes remain unmonitored

When provided with a half-decent geophysical monitoring network, volcanologists are pretty good at predicting when an eruption might occur a week or two before it takes place. Pinpointing in advance the next Tambora is a different kettle of fish, especially given that there are at least 1,300 active volcanoes around the world, only a fraction of which are currently monitored. We can, however, try and narrow the odds a little. Bearing in mind that half of the 20 biggest eruptions since 1800 occurred at volcanoes that – like Tambora – had not erupted in historic records, we should perhaps focus on those seemingly innocuous volcanoes that have been quiet for millennia, especially those that are showing signs of life. Restless Mount Paektu on the border between North Korea and China immediately springs to mind, along with steadily swelling Uturuncu in southwestern Bolivia and the rapidly inflating Laguna del Maule volcano in Chile.

Could Mount Paektu be the next volcano to erupt?



An infrared view of Tambora, taken from space

> **"The weather of 1816 supplied the brooding backdrop that inspired Mary Shelley to write *Frankenstein*"**

on the three-year escalation of activity that preceded Tambora's climactic explosion, it may be that we will have a decent lead-in time before the next great volcanic blast, giving us the opportunity to plan for the event. The problem is that we are still not able to determine if increasing restlessness at a candidate volcano will end in an Earth-shattering eruption or a return to slumber. With a number of potential future Tamboras already bubbling and swelling in various regions, the stage may be set for the next 'big one'.

So, given what we now know about massive eruptions and the potentially disastrous impact they can have on the climate, will we be ready? Sadly, it would come as no surprise if we were caught out. After all, we were completely unprepared for the relatively minor eruption of Iceland's Eyjafjallajökull in 2010, which played havoc with air travel across Europe, even though it was only a little over half a century since Icelandic ash last invaded European airspace. Clearly, when it comes to the impact of volcanic eruptions, we have very short memories. Before it's too late, let's hope that we don't forget the important lessons Tambora has taught us about the devastating and far-reaching consequences a single volcanic blast can have for our world. ■

BILL MCGUIRE is Professor Emeritus of Geophysical and Climate Hazards at UCL. His current book is *Waking The Giant*

BBC FOUR

To watch a *Journeys Into The Ring Of Fire* clip about Mount Tambora, visit **http://bbc.in/uSCjTi**

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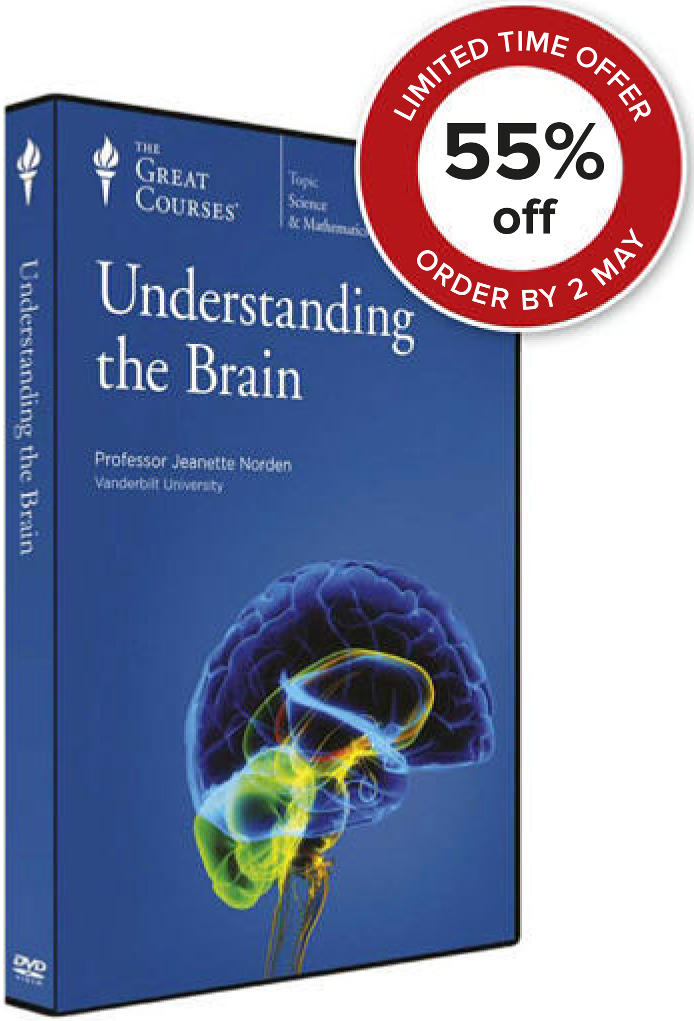

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Q&A

YOUR QUESTIONS ANSWERED

BY OUR EXPERT PANEL

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Susan is a visiting psychology professor at the University of Plymouth. Her books include *The Meme Machine*

DR ALASTAIR GUNN
Alastair is a radio astronomer at the Jodrell Bank Centre for Astrophysics at the University of Manchester

ROBERT MATTHEWS
After studying physics at Oxford, Robert became a science writer. He's Visiting Reader in Science at Aston University

GARETH MITCHELL
Starting out as a broadcast engineer, Gareth now writes and presents *Click* on the BBC World Service

LUIS VILLAZON
Luis has a BSc in computing and an MSc in zoology from Oxford. His works include *How Cows Reach The Ground*

EMAIL YOUR QUESTIONS TO questions@sciencefocus.com
or post to *Focus* Q&A, Tower House, Fairfax Street, Bristol, BS1 3BN

Q **KAREN OLSEN,** LEICESTER

How much of the electromagnetic spectrum does the Sun emit?

A THE SUN EMITS radiation right across the electromagnetic spectrum, from extremely high-energy X-rays to ultra-long-wavelength radio waves, and everything in-between. The peak of this emission occurs in the visible portion of the spectrum. Different wavelengths of light generally come from different regions of the Sun's atmosphere or are due to particular atoms radiating at specific wavelengths (spectral emission lines). Visible light, for example, comes from the photosphere (or surface) whereas most infrared light comes from the lower chromosphere just above. Much of the high-energy UV and X-ray photons come from the Sun's outer atmosphere (called the corona). This gives astronomers the ability to explore different solar features, constituents or processes simply by selecting a particular wavelength of light to observe. That is why NASA's Solar Dynamics Observatory, for example, has an array of instruments that cover a wide range of wavelengths simultaneously. **AG**

NASA's Solar Dynamics Observatory can show the range of wavelengths that the Sun emits

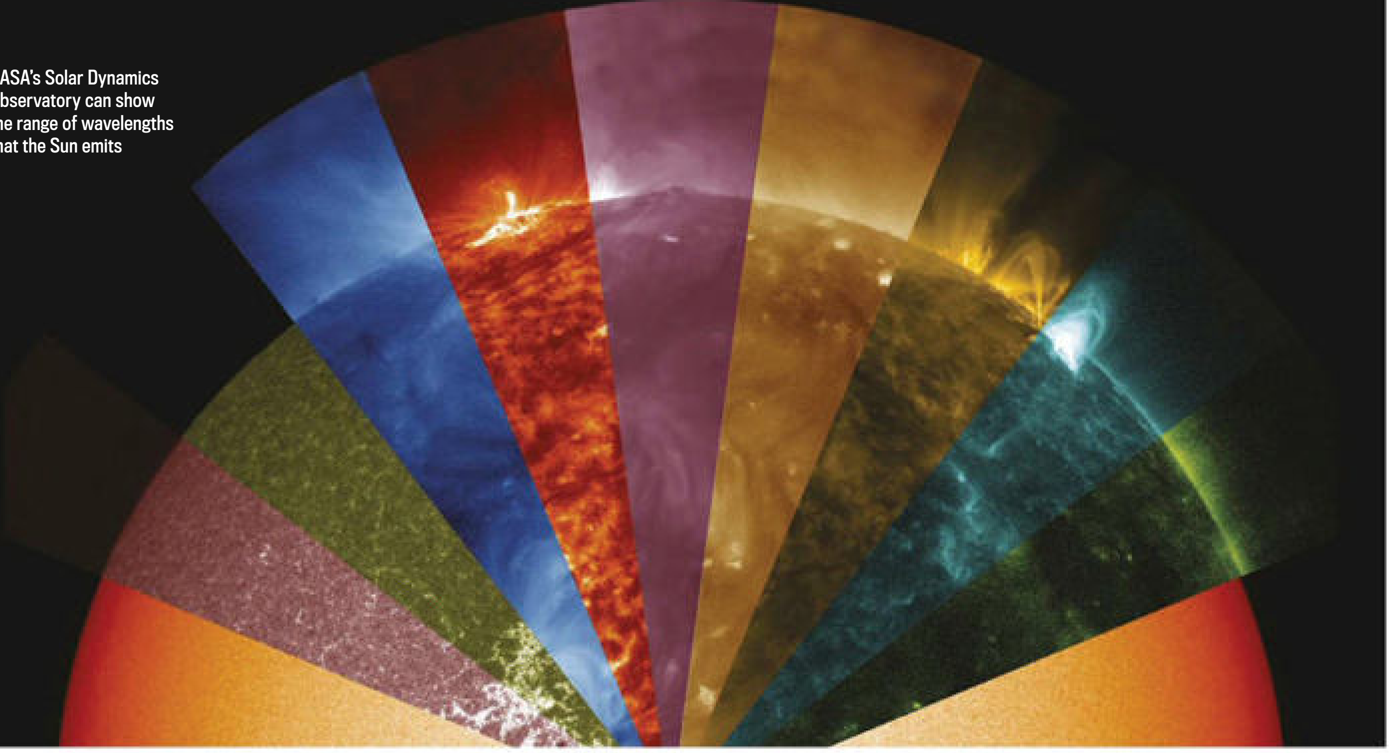


PHOTO: NASA/SOHO

In Numbers

307

kilometres is how far a team sent quantum keys, which are used to encode messages. This beat the previous record of 150km

Q **MIKE REYNOLDS**, POOLE

Why do we close our eyes when we're trying to remember things?

A TO AVOID DISTRACTION. When we imagine something, our brains use the same systems they use for seeing, touching or listening. If you're trying to recall a past event, you need to free up the visual cortex to conjure up the images.

Researchers asked people to watch a short video and then answer questions about it. Those who closed their eyes or looked at a blank screen remembered more than those who watched a display of nonsense images or heard unfamiliar words. In other tests, they had to recall details from a crime video with their eyes open or closed. They remembered more correctly with their eyes closed. They also recalled sounds from the video better when their eyes were shut. **SB**

Q **CHARLIE MACK**, UCKFIELD

Where is the loudest place in the Universe?

Some 80 million trees were flattened following the Tunguska Meteor impact

A SOUND IS THE movement of a pressure wave through matter. Since space is almost (but not quite) a complete vacuum, sound does not propagate easily through it. However, where matter is denser, such as in the atmospheres of planets, within stars, in gas clouds or in environments surrounding black holes, sound waves are thought to be common.

The 'loudest' sounds in the Universe are the ones carrying most energy. A rough estimate of the loudness of the Big Bang is about 100dB to 120dB. Although this is near the human ear's pain threshold, it is by no means the loudest thing known to us. It is estimated that the loudest thing on Earth was probably the explosion of the Tunguska Meteor (1908) at about 300dB. Perhaps where planets or black holes collide, or where supernovae explode, there may be sounds more powerful than this. **AG**

Q **ALASDAIR CLYDE**, GLASGOW

How do fossils form?

Fossilisation is rare, but it can provide valuable information for scientists

A WHEN AN ANIMAL or plant dies, it is usually eaten or rots away. But it occasionally gets buried in the silt on the seabed, on a riverbank or by volcanic ash. This can slow down the decay processes enough that the surrounding sediment has a chance to harden before the organism decays, leaving an imprint of the animal's body – or at least its bones. More rarely, other minerals might percolate into the body tissues and harden to form a positive cast of the animal. Fossils can also be squeezed at great pressure between the layers in the rock, until only a thin carbonised smear of the original tissues is left. **LV**

Q **JACK TEALE**, MELBOURNE, AUSTRALIA

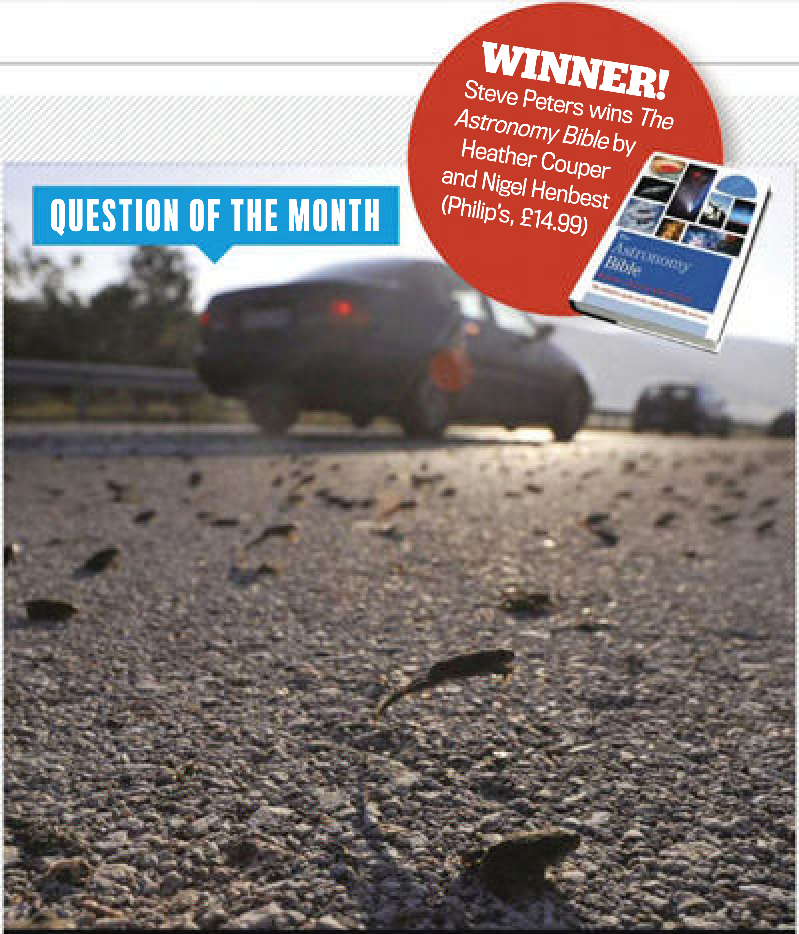
Why do we get goosebumps when listening to music?

A IT'S DOWN TO the flow of dopamine in the brain's reward pathways. The effect is called 'musical chills' and includes raised heart rate and temperature, dilated pupils, goosebumps and tingling down the spine. Oddly, dopamine peaks several seconds before the goosebumps, perhaps because music tempts us into constantly predicting what is coming next. Goosebumps tend to come when a new instrument or voice enters, or when the volume, key or form shifts. Musical preferences make no difference to susceptibility. Sad music is more effective, but the chills are still experienced as positive. **SB**

PHOTO: PRESS ASSOCIATION X2, GETTY, ISTOCK, NASA

QUESTION OF THE MONTH

WINNER!
Steve Peters wins *The Astronomy Bible* by Heather Couper and Nigel Henbest (Philip's, £14.99)



Amphibians may be able to detect changes in groundwater prior to earthquakes taking place

Q **STEVE PETERS,** BY EMAIL

Can animals sense an impending earthquake?

A WHEN AN EARTHQUAKE strikes, different vibrations travel through the ground at different speeds. The Primary (P-wave) vibrations travel about twice as fast as the Secondary (S-wave) vibrations that do most of the actual shaking. P-waves are generally too subtle to be felt by humans, although seismographs will pick them up. But some animals may be able to detect P-waves before the S-waves arrive. This would give them less than two minutes' notice for any quake near enough to affect them.

Stories of snakes leaving their burrows, dogs barking excessively or birds flying in unusual patterns, days or weeks before an earthquake actually takes place are more contentious.

But there may be subtle changes prior to an earthquake that animals are able to detect. A 2011 study at The Open University found that the stresses that build up along earthquake fault lines cause pockets of positive charge to move through the rocks to the surface and will trigger chemical changes in the groundwater. This could have been the reason that toads suddenly left their breeding pond a few days before the earthquake that hit L'Aquila, Italy in 2009. Their pond was 74km away from the earthquake's epicentre.

The positive charge could even affect the electromagnetic fields that bats and birds use for navigation, but we don't have any direct evidence for this yet. **LV**

Q **ALEX ROUND**, LONDON

Can fingerprints change during a lifetime?

My, what lovely prints you have!

A THE PATTERN OF loops and whorls on your fingerprints was fixed three months before you were born. You can scar your fingerprints with a cut, or temporarily lose them through abrasion, acid or certain skin conditions, but fingerprints lost in this way will grow back within a month. As you age, skin on your fingertips becomes less elastic and the ridges get thicker. This doesn't change your fingerprint, but it's harder to scan or take a print from it. **LV**

Typical. You go on holiday to Venus and the weather is still terrible

Q **DONALD GILL,** DEVON

Can lightning occur in space?

A LIGHTNING IS A sudden electrostatic discharge between regions of differing electric potential. It has been observed on Venus, Jupiter and Saturn, as well as Earth. In space there is little material to act as a conductor of charge. Traditional lightning, therefore, is probably rare. Processes similar to lightning have been observed in electromagnetic fields around black holes as well as in highly ionised clouds of gas and dust called nebulae. **AG**

Q **ALEX MELLISH,** READING

What is the smallest shark and what does it eat?

A THERE ARE SEVERAL candidates among the dogfish sharks but the smallest is probably the dwarf lantern shark (*Etmopterus perryi*), which is about 21cm long. It lives off the coast of Colombia. Light-emitting organs on its belly attract its prey, which includes small fish and shrimps. **LV**

Daa-dum...
daa-dum...
da-dum da-dum
da-dum da-dum

Q **ALFRED C GAUCI,** MALTA

How do rats survive the toxic gases in sewers?

A THE MOST TOXIC component of sewer gas is hydrogen sulphide (H_2S), which is produced by bacteria decomposing organic matter in oxygen-starved environments. H_2S is deadly to humans at concentrations as low as 300 parts per million. The lethal concentration for rats is about 1.5 times higher, but they probably just try to avoid gas pockets. H_2S is heavier than air, so it collects in the lowest part of the sewer system. Some humans can detect its rotten egg smell at concentrations of just five parts per billion. **LV**

Did you know?

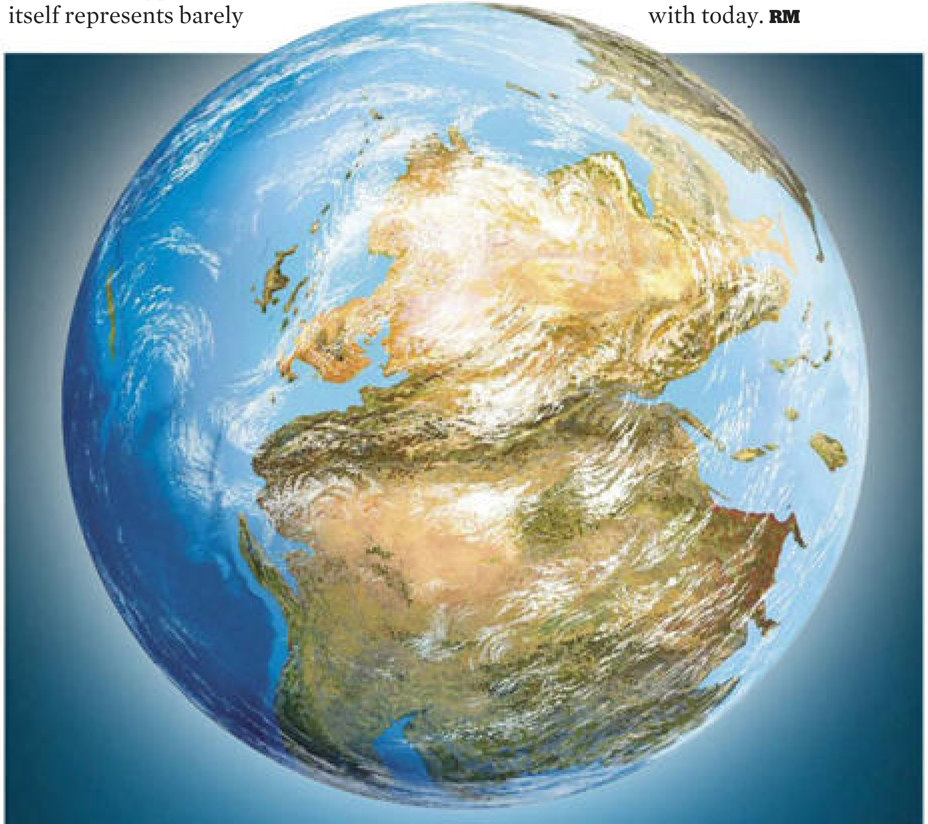
Twenty people, all over 1.52m tall, crammed into a Smart car in Los Angeles on 20 September 2011

Q **AURIOL MATTHEWS**, LONDON

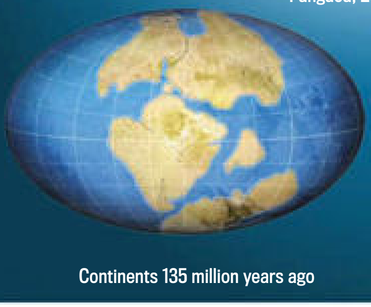
Why is most of the world's landmass in the northern hemisphere?

A THE GREEK PHILOSOPHER Aristotle argued that there simply had to be a huge landmass south of the Equator, in order to balance out the vast amount to the north of the planet. The idea of 'Terra Australis' persisted for over 2,000 years and even appeared on maps between the 15th and 18th Centuries. It was finally debunked by Captain James Cook's expedition to find it in the 1770s.

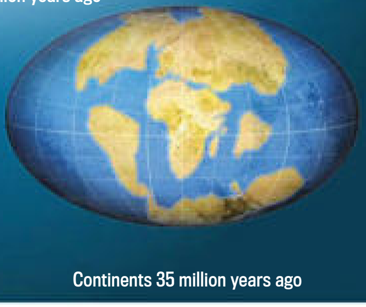
It's now recognised that, despite appearances, the continents aren't that important, being merely slightly thicker parts of the upper crust, which itself represents barely 1 per cent of the volume of the Earth. Satellite studies of the distribution of gravity across the entire planet reveal little difference between the amount of mass in the northern and southern hemispheres. As such, the arrangement of the world's continents has little significance – and, in any case, has changed over time. Around 200 million years ago, the Earth's surface was dominated by the so-called Pangaea supercontinent, much of which was actually south of the Equator. Pangaea broke up over time to form the modern continents that we are familiar with today. **RM**



Pangaea, 200-300 million years ago



Continents 135 million years ago



Continents 35 million years ago

PHOTO: SEAPICS.COM, SCIENCE PHOTO LIBRARY X3, ISTOCK X3, DAVID TENENBAUM/UNIVERSITY OF WISCONSIN-MADISON

Q Where could the next natural disaster strike?

Around the world, catastrophic events are waiting to happen. **Bill McGuire** reveals where nature is set to wreak havoc next

A JAMAICA, WEST INDIES

KINGSTON

Almost three-quarters of Jamaica's housing is unlikely to survive the violent shaking of a serious quake

THE JAMAICAN CAPITAL is no stranger to destructive earthquakes and the threat is once again becoming apparent. Kingston lies on the same fault that spawned the devastating 2010 Haiti quake that claimed 316,000 lives. Seismologists are warning that Jamaica could be next. In 1907, Kingston was battered by a magnitude 6.5 earthquake that destroyed or damaged almost every building and resulted in close to 1,000 deaths. Three centuries earlier, Kingston's predecessor settlement, Port Royal, was obliterated by a magnitude 7.5 quake and resulting tsunami that left little standing and few residents alive. A quake of up to this magnitude is now on the cards again. With close to 75 per cent of the island's buildings described as 'informal', another Caribbean catastrophe could be in the making.

A CHILE–ARGENTINA BORDER

LAGUNA DEL MAULE

Everything looks calm from above, but there is gas-rich magma bubbling below the surface

COULD THE NEXT volcanic super eruption be brewing in South America? The evidence for huge blasts occurring at the Laguna del Maule volcano is clear: its location is marked by a giant, lake-filled crater measuring 25x15km. Over the last seven years or so, the volcano has been swelling at an astonishing rate of up to 25cm a year. This prompted the Volcano Observatory of the Southern Andes to declare a yellow alert in 2013, flagging the possibility of an eruption within months to years.

Recent research suggests that the swelling is linked to an enormous (5x10km) body of rhyolite magma lurking six kilometres or so beneath the surface. Rhyolite is a particularly sticky, gas-rich magma that drives the biggest and most violent volcanic eruptions. A new $3m (£1.94m) monitoring programme in the area hopes to find out more.

A WESTERN UNITED STATES

CALIFORNIA

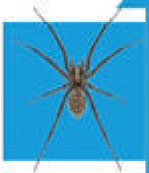
Racetrack Playa is a well-known dry lake in California. Will the rest of the state soon resemble it?

CALIFORNIA IS SUFFERING at the hands of a once in a millennium megadrought. Minimal rainfall and a reduced mountain snowpack have led to the driest conditions for at least 1,200 years. In 2015, January – normally the wettest month – was the driest on record, and no rain fell in San Francisco. In the first half of 2014, drought conditions cost the agricultural industry $2.2bn (£1.43bn) and 17,000 jobs. As farmers suck up groundwater to compensate for reduced supplies from reservoirs, 2015 could be even worse as wells start to go dry. The sustainability of the state's food production, which supplies up to half the US's fruit and veg, is being questioned.

BILL MCGUIRE is Emeritus Professor of Geophysical and Climate Hazards at University College London and wrote *Waking The Giant*

TOP TEN

PHOBIAS



1= Arachnophobia

Fear of spiders
Incidence: 33 per cent

1= Ophidiophobia

Fear of snakes
Incidence: 33 per cent

3. Astraphobia

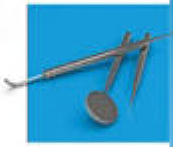
Fear of thunder/lightning
Incidence: 15 per cent

4= Trypanophobia

Fear of needles
Incidence: 10 per cent

4= Claustrophobia

Fear of enclosed spaces
Incidence: 10 per cent



6. Odontophobia

Fear of dentists
Incidence: 9 per cent

7. Aviophobia

Fear of flying
Incidence: 7 per cent

8. Acrophobia

Fear of heights
Incidence: 5 per cent

9. Cynophobia

Fear of dogs
Incidence: 3 per cent

10. Agoraphobia

Fear of public spaces
Incidence: 2 per cent

PHOTO: ISTOCK X12, GETTY X2

Q **SIMON LEWIS,** BEDFORD

What's the most amazing result in mathematics?

A A POPULAR CHOICE is Euler's Identity, which shows that raising the endless number 'e' (roughly 2.718) to the power of pi, multiplied by the impossible square-root of -1, and then adding the result to 1 produces... zero. How such a crazy mix of numbers leads to such a simple result defies common sense.

No less baffling is the Banach-Tarski Paradox, which shows that a solid ball can be cut into five special shapes and re-assembled to make two exact, perfectly solid replicas of the original ball. Admittedly, the shapes have to be pretty special – specifically, infinitely jagged, which isn't possible in the real world.

Arguably, the craziest of all results does have real-world implications. It's the sum of all the integers, 1+2+3+4 and so on, all the way to infinity. On the face of it, this must add up to infinity. The correct answer, however, isn't even a positive whole number: it's minus 1/12. This result emerges from something called analytic continuation of the Riemann zeta function. Physicists have successfully tested its implications in theories about the sub-atomic world. **RM**

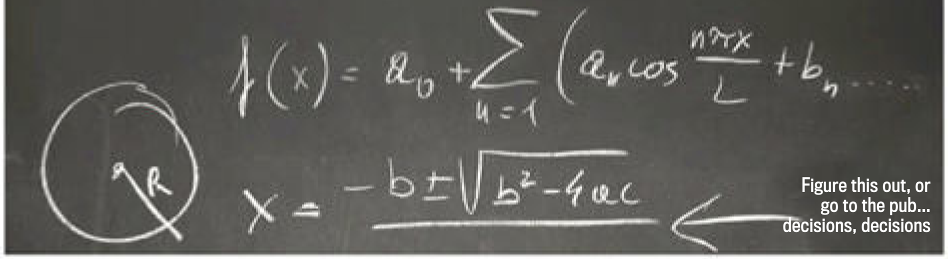
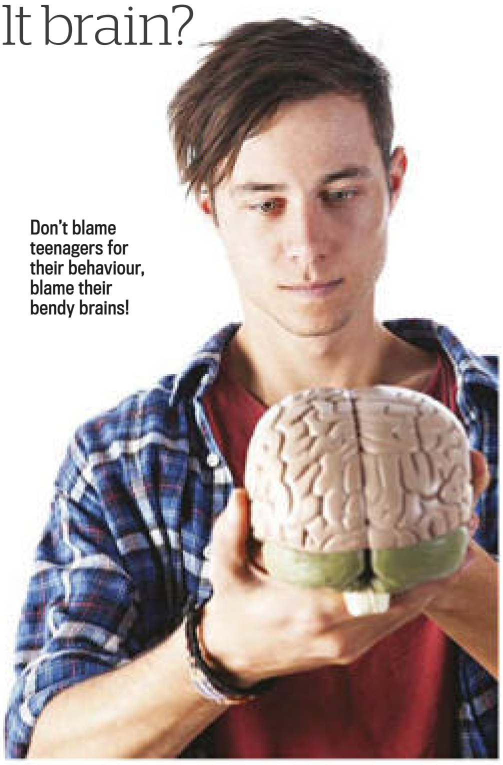

f(x) = a₀ + Σ (aₙ cos nπx/L + bₙ ....
n = 1
πR
x = −b ± √b² − 4ac

Figure this out, or go to the pub... decisions, decisions

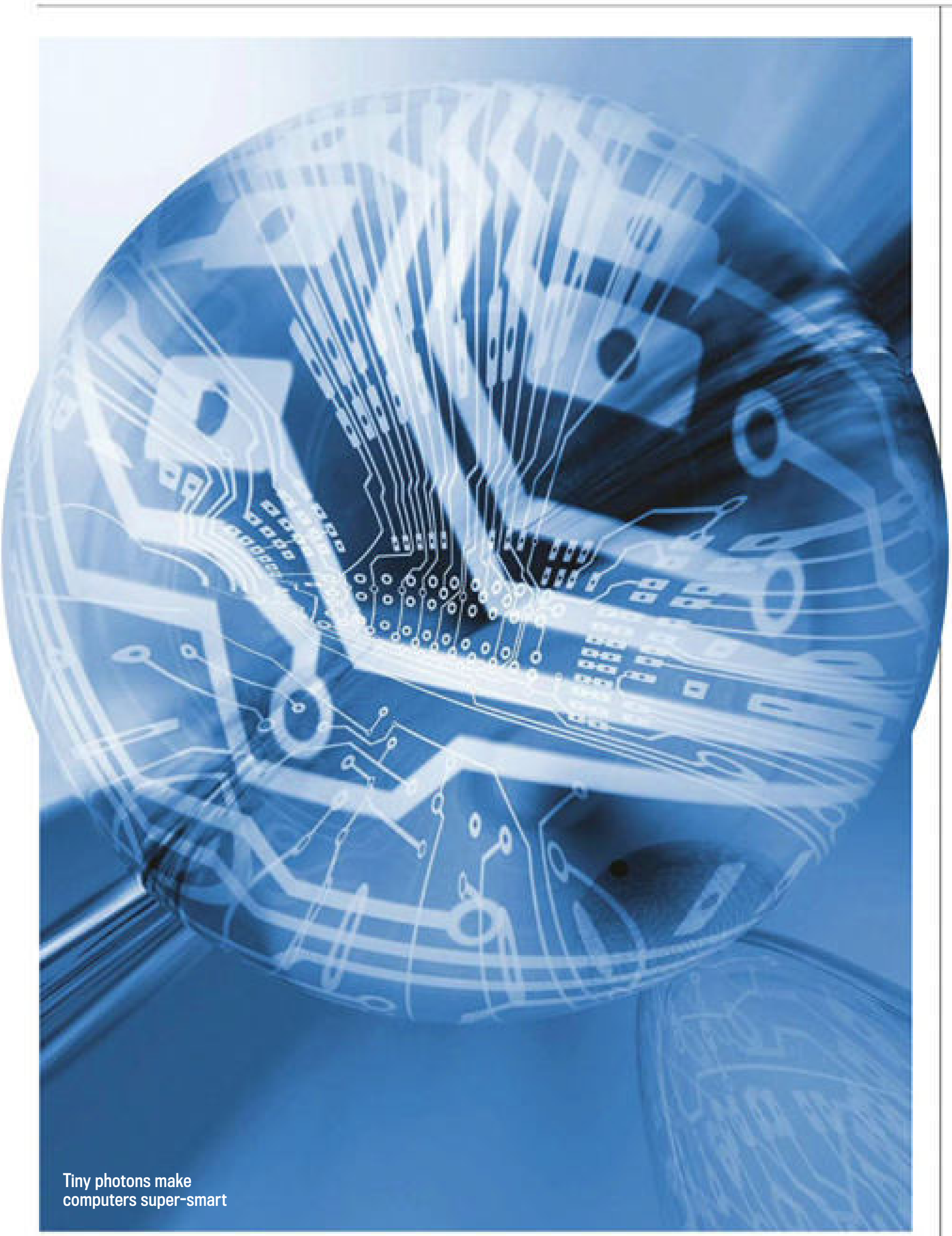
Q **ANNE PHILIPS**, ANDOVER

How does a teenage brain differ from an adult brain?

A A TEENAGE BRAIN doesn't grow as fast as a child's, but its organisation keeps changing right up to the early 20s. Synapses in the teen brain are radically pruned, leaving only the most frequently used. The brain's grey matter (cell bodies of neurones) peaks in volume in early adolescence. The axons (long fibres that communicate between cells) become gradually covered with myelin. This makes signals travel faster, but makes it harder for new synapses to form. In the teenage brain, myelination is not complete so the brain is slower but more flexible. The last parts of the brain to change are the frontal lobes, which are responsible for impulse control and response inhibition. This may explain why teens can be impulsive, easily distracted and poor at setting sensible goals. The advantages of this may lie in flexibility at a time of rapid change and adaptation. **SB**



Don't blame teenagers for their behaviour, blame their bendy brains!



Tiny photons make computers super-smart

Q **RANDALL BARFIELD**, SOUTH CAROLINA, USA

How does a quantum computer work?

A QUANTUM COMPUTERS RELY on the characteristic that individual particles such as photons can exist in many places simultaneously. At any one time we only know the probability of the photon being in a given state. So instead of breaking a problem up into 1s and 0s as in a classical computer, we assign it to a quantum computer by priming the initial states of pairs of photons. Each quantum bit – or qubit – is not therefore either 1 or 0, it is both at the same time. A series of qubits represents a range of values at once and thus a quantum computer performs multiple calculations simultaneously. Unlike a classical computer, we don't get a discrete set of calculations but a series of values that we know to within a certain probability. That might sound rather useless, but problems like decrypting ciphered information are ideally suited to probabilistic computation. Being able to solve many problems at once means that such machines could rapidly break encryption that would be beyond classical computers. **GM**

Q **RICHARD O'NEILL,** GLASGOW

How long do consoles spend in development?

A DETAILS ON THE latest consoles, the Xbox One and PS4, are shrouded in secrecy. But generally, it takes three to five years to develop a console. Sony's earlier machine, the PS3, launched in November 2006 after many delays. The first plans were drawn up as far back as 2000, when Sony teamed up with Toshiba and IBM to develop the console's bespoke Cell CPU. Microsoft is a bit faster – the Xbox 360 launched just before Christmas 2005 and began development about three years previously. **GM**

Sony's PS3 took around six years to develop

Q **WAEL ALSALLAMI**, YEMEN

Why does putting a finger down your throat make you vomit?

A NERVES IN THE roof of your mouth, back of your tongue and throat trigger the pharyngeal or 'gag' reflex if they're touched by anything big enough. Young babies have a gag reflex sensitive enough to be set off by solid food to help protect them from substances that they aren't able to digest. Later, the gag reflex prevents choking but about one in three people don't seem to have a gag reflex at all. **LV**

"I *really* shouldn't have eaten that dodgy kebab"

Q **BECCA JOHNSON**, DURHAM

How did the zebra get its stripes?

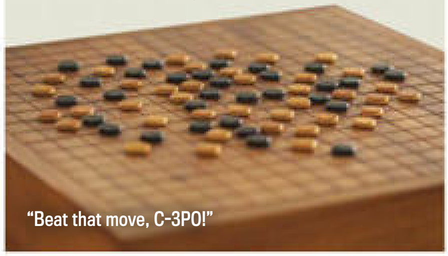
A THIS MYSTERY HAS ‘finally’ been solved many times over the years, with explanations ranging from camouflage to a deterrent against parasites. The most compelling evidence – published this January by scientists in the US – suggests the main benefit comes from the contrasting way that black and white stripes absorb heat. Black gets hotter than white, creating cooling swirls of airflow over the zebra’s skin. **RM**

“I’m so cool with my monochrome stripes”

Q **PETER TOYNE**, LIVERPOOL

Are there any games at which people can still beat computers?

A HUMANS STILL HAVE the edge in the game of Go. Like chess, it’s played on a chequered board. But the board has more squares (19x19) and each piece can perform many more potential moves. While chess becomes more computationally straightforward as the game progresses and pieces are removed, Go requires more judgment and intuition. These attributes are more suitable to human intelligence than machine algorithms. **GM**



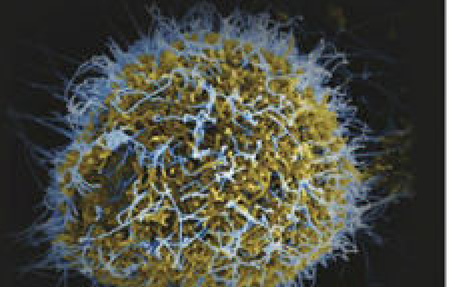
“Beat that move, C-3PO!”

Q **TONY FERRER,** HIGH WYCOMBE

How does a virus mutate so quickly?

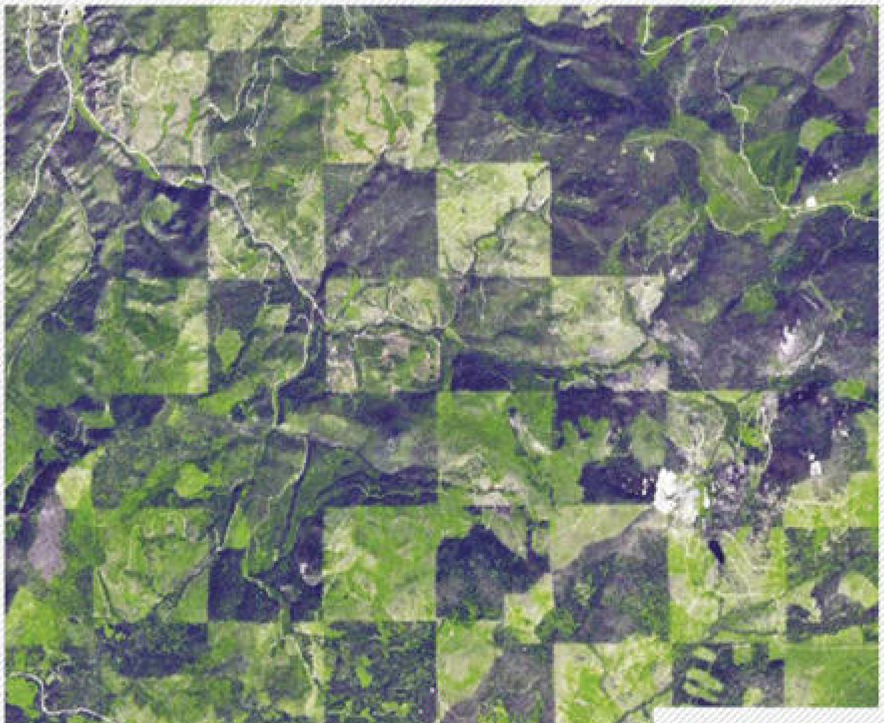
A NOT ALL VIRUSES do mutate quickly. DNA viruses, like smallpox, have mutation rates that are roughly the same as bacteria and other microorganisms. But viruses that use the single-stranded RNA, instead of DNA’s double helix as their genetic material, mutate over 100 times faster. On average, an RNA virus mutates one letter of its genetic code almost every time it replicates. They do this by not proofreading their work.

In contrast, DNA-based organisms have special enzymes that spot errors and redo that section of DNA, but RNA viruses lack this. This may be an adaptation to allow them to make lots of hastier, inaccurate copies of themselves to overwhelm their host before the immune system is able to respond. Most mutations are bad for a virus, so RNA viruses are limited to very small genomes to give them a decent chance of making an error-free copy. **LV**



Ebola virus (blue) budding from an infected cell

WHAT IS THIS?



KNOW THE ANSWER?
Submit your guess now at
sciencefocus.com/qanda/what

LAST MONTH’S PICTURE →
Stephen Aitchison correctly guessed the phenomenon of sprite lightning

PHOTO: SCIENCE PHOTO LIBRARY, ALAMY, GETTY X2, PRESS ASSOCIATION

Q **LIZZIE DENNIS,** COLCHESTER

What's the difference between an internet meme and a teme?

A INTERNET MEMES ARE created, copied and selected by us. Darwinism claims that when any kind of info is copied, varied and selected then evolution must happen. This information is called a 'replicator'. Genes were the first replicator on Earth, and memes the second. Memes appeared when early humans began to imitate, meaning they could copy, vary and select ideas, skills, stories and technologies.

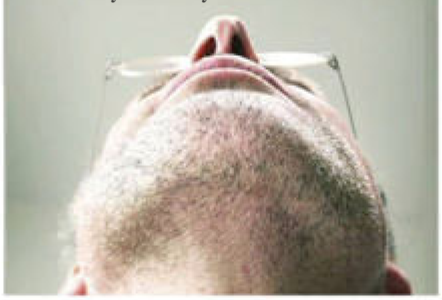
Digital technology may be allowing a third replicator, temes, to emerge – digital info that evolves without intervention. We created the machinery that makes this possible but are no longer in control of it. This idea may or may not be valid, but it helps us think about the evolution of all that stuff in the web. **SB**

Grumpy Cat disapproves of the *Focus* Q&A page

Q **ALAN CLARK,** LIVERPOOL

Why is 48 hours' growth of facial hair so uncomfortable?

A BEARDS GROW BY about half a millimetre a day. For the first 24 hours, your beard is just climbing back out of the follicles and barely pokes clear of your chin. Once the hairs get a little longer they can rub against nearby skin, particularly under your chin and on your neck where the skin wrinkles up as you move your head. As your beard gets longer, the hairs bend more and are less likely to stab your skin. **LV**



Q **PHILIP JONES,** CAERPHILLY

Why does the human body reject transplanted organs but not blood transfusions?

Dracula's buffet

A BLOOD TRANSFUSIONS ARE rejected, if incompatible blood types are mixed. But donated blood is normally centrifuged to separate out the different components. In an ordinary blood transfusion, all you're receiving is the red blood cells. Apart from a few extremely rare cases, everyone's red blood cells fall into four main groups (A, B, AB and O). This makes it much simpler to match donor and recipient – and in emergencies, you can safely give type O negative blood to anyone. Organ tissues have compatibility types determined by much more complicated genetics with thousands of possible combinations, so finding a good match from unrelated donors is much less likely. **LV**

Q **DAN SULLIVAN,** BY EMAIL

Why aren't planes and cars given drag-reducing dimples like golf balls?

A THE BEST WAY to cut drag depends on the shape of the object. Blunt, round golf balls benefit from dimples because they help wrap the oncoming air smoothly around the ball, reducing turbulence. Sleek objects like planes experience a different type of drag and so wouldn't benefit, but blunter ones like cars just might. **RM**

NEXT MONTH Over 20 more of your questions answered

For even more answers to the most puzzling questions, see the Q&A archive at **www.sciencefocus.com/qanda**

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THE FUTURE OF GADGETS

TECH HUB

EDITED BY **DANIEL BENNETT**

THIS MONTH

BILL THOMPSON
CCTV gets smart
p79

APPLIANCES OF SCIENCE
p81

ULTIMATE TEST
High-res audio
p82

The upcoming Pebble Time comes in a standard version (far left) and premium models going by the Pebble Time Steel moniker

ON THE HORIZON

PEBBLE TIME

The smartwatch to take on Apple

getpebble.com

WORDS: **DANIEL BENNETT**

THIS MONTH, ONE gadget is bound to grab the headlines: the Apple Watch. Days before it goes on sale in April, devotees will make their annual pilgrimage to the company's shops and the news crews won't be far behind. But while the world eyes up Apple's first timepiece, there's another new smartwatch that's caught our attention.

The Pebble Time takes an entirely different approach to the smartwatch. While its competition focuses on powerful processors, sharp screens and amazing apps, Pebble has decided not to simply slap a smartphone on your wrist.

For a start, there's the screen. While the likes of Apple and Samsung have opted for high-resolution, battery-flattening touchscreens, Pebble has opted for an E Ink display like those found on an ereader. But this is no black and white Kindle. Pebble uses a full colour (64 colours, to be precise) display with a refresh rate that will allow for fluid animations. It's technology that we first saw back in 2011, but to date no company has successfully implemented it. A traditional E Ink screen

PEBBLE TIME

DIMENSIONS:	47 x 37.5 x 9.5mm
TOUGHNESS:	WATERPROOF
DISPLAY:	64-COLOUR E INK (182PPI)
CONNECTIVITY:	BLUETOOTH
SENSORS:	ACCELEROMETER, COMPASS, MIC
PROCESSOR:	100MHZ ARM PROCESSOR
STORAGE:	8 APPS
BATTERY LIFE:	7 DAYS
PHONE CALLS:	NO
PRICE:	FROM $199 (£132)

APPLE WATCH

DIMENSIONS:	39 x 33 x 11mm OR 42 x 36 x 11mm
TOUGHNESS:	WATER-RESISTANT
DISPLAY:	RETINA DISPLAY, TOUCHSCREEN
CONNECTIVITY:	BLUETOOTH, WI-FI
SENSORS:	HEART RATE, ACCELEROMETERS, GPS, MIC
PROCESSOR:	APPLE S1
STORAGE:	8GB
BATTERY LIFE:	18 HOURS
PHONE CALLS:	YES
PRICE:	FROM £299

➜ uses black and white microcapsules to create images. The white bits are positively charged and the black areas are negative. By changing the charge at the surface of the screen, an E Ink display can draw white or black capsules to the surface to create an image. Over the years E Ink screens have improved by being able to change the charge state faster and more accurately. A colour screen is created by placing an adjustable colour filter over the top that has a red, blue, green and white segment for each pixel. As natural light passes through the filter, it reflects off the white particles and back through the filter to produce different colours. Unlike traditional LED displays, it actually works better in the Sun. There's only really one downside – the resolution. But as you might have noticed in the latest Kindle, E Ink displays are getting sharper every year.

There is another massive advantage to the Pebble Time: low power consumption. Pair that with its frugal processor and you get a smartwatch that only needs to be charged once a week. In contrast, the Apple Watch will last just 18 hours before it needs to be juiced up.

But it's not just the Pebble's pared down hardware that appeals. The company has come up with an entirely new interface for its watch. While other companies have built smartwatches you can write emails on or take calls with, Pebble has concentrated on time, believe it or not. One button takes you back in time to look at messages, missed calls and updates from the past. Another button takes you forward to remind you of upcoming meetings and to-do lists. Every app you download (there are already 6,000 of them) feeds into this system to draw up your own personal timeline. If you need to respond to anything you can send a reply or make notes by dictation. We'll reserve final judgment on the Pebble Time and Apple Watch until we test them later this year, but for now we know which smartwatch we'd be queuing for...

DANIEL BENNETT is the reviews editor at *BBC Focus Magazine*

TECHOMETER

WHAT'S HOT

HYDROGEN FUEL

The UK's first hydrogen fuelling station has opened in Aberdeen, Scotland. The station will be fuelling the city's 10 new hydrogen-powered buses that have started ferrying commuters around the city pollution-free. The only emission is water vapour and the buses are almost completely silent. Six more hydrogen stations for public use are due to open this year in anticipation of the Toyota Mirai - the first hydrogen car to go on sale in Europe.

WHAT'S NOT

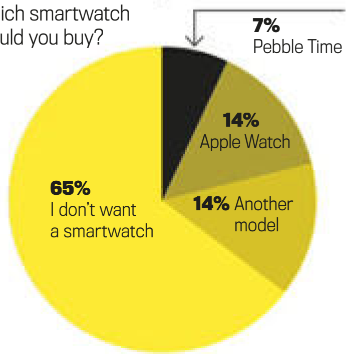
PLAYSTATION MOBILE

The online store, which sells classic PlayStation games and independent titles for Android smartphones and PlayStation handheld consoles, will close this year. The store will stop issuing content after 15 July, and in-app purchases and downloads will be disabled from 10 September. If you've purchased content in the past via the store, it's worth downloading any software you want to keep now.

PlayStation.Mobile

READER POLL

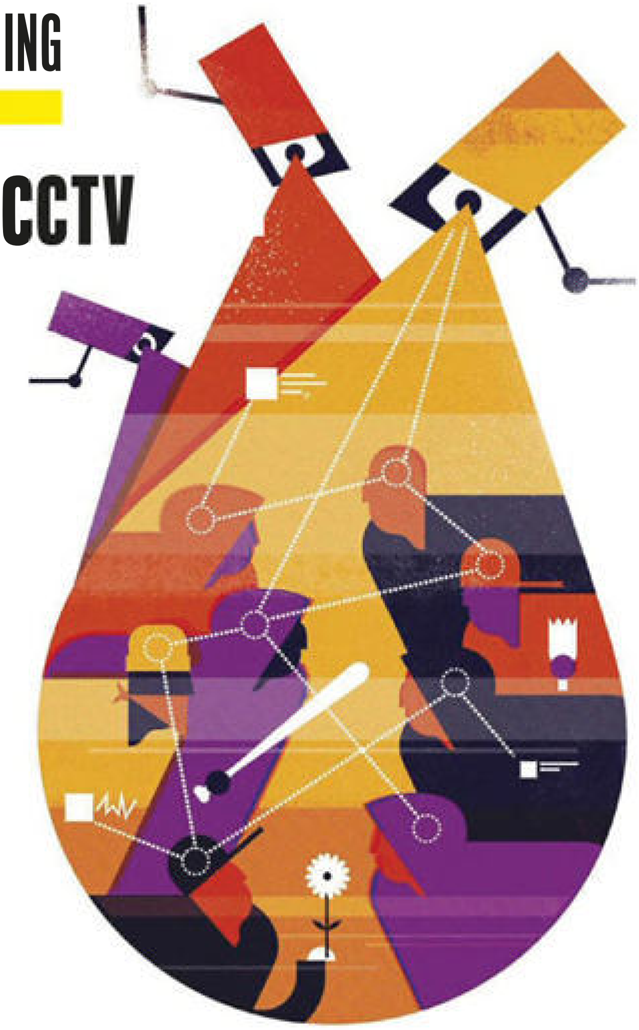
Which smartwatch would you buy?



ILLUSTRATOR: DEM ILLUSTRATION

THE NEXT BIG THING

HIGH-TECH CCTV



HERE IN THE UK, we're used to being watched as we wander the streets, travel on trains and buses or sit in bars. The darkened domes of small cameras are a pervasive aspect of public space, with around six million cameras installed and transmitting images as we go about our lives.

We're the most heavily infested country in the world, and the argument against this form of surveillance seems to have been long lost.

The vast majority of these cameras are dumb, simply transmitting images back to control centres where human operators monitor them, or feeding vast banks of recorders that can be used to discover just what happened on the 38 bus at 3am last Friday.

Some go further, and we have systems that involve automatic image processing, like the number plate recognition systems in use in petrol stations. Now we're on the verge of a major change in the way surveillance works and the machines are going to start responding to us.

A project at Cardiff University is working on a way to determine whether the behaviour of a crowd indicates that a fight is about to break out, so the police can be called.

But what happens if the police arrive and no fight happens? It's a bit like the idea of 'pre-crime' in the film *Minority Report* – can you be sure that the crime you 'stopped' would actually have happened, since your intervention changed the future? And what if it wasn't a fight, but just a lively group of young men having a good time?

These systems are still experimental, but we can expect a lot of investment, if only because of the high costs of paying people to watch CCTV coverage. Software that does the job could be attractive.

Military technology that's being developed as part of the US drone programme may make its way into civilian CCTV systems. Drones that scan large areas looking for signatures that indicate a threat or a terrorist training camp would be very useful, although for the moment there would still be a human in the loop to decide whether to launch missiles.

If we do find ourselves overseen by algorithms, it opens up the possibility that cities will start to express different social and cultural norms by tweaking their surveillance systems. Perhaps Rio and Barcelona will be more tolerant of raucous crowds than Manchester or Rouen. Berlin might clamp down on loitering while Amsterdam encourages it. As our smart cities start to develop personalities, maybe we'll choose where to live because we get on with the city itself, not the people who live in it.

BILL THOMPSON contributes to news.bbc.co.uk and the BBC World Service

COMING SOON

3 MONTHS

NEW MACBOOK

Apple's newest laptop comes with just a single port that provides power and USB connectivity. This cuts the thickness down to just over 13mm and the weight to 920g. *Apple.com*

Zano
This palm-sized drone can take off from your hand and will autonomously film you by following your smartphone around. *Flyzano.com*

Apple Watch
By the end of April, the Apple Watch will have arrived. Prices range from £299 to £13,500. *Apple.com*

6 MONTHS

HTC VIVE

Valve – the company behind the game *Half-Life* and PC game store Steam – has partnered up with HTC to create its own virtual reality system. *Htcvr.com*

Oculus Rift
We're still waiting for the company that kickstarted the virtual revolution to bring its first headset to market. But a recent leak suggests it's aiming to sell its first units before the end of summer. *Oculus.com*

Tesla model D
The next car from Tesla – inspired by the McLaren F1's specs – will arrive this summer. It'll come with four-wheel drive and an autopilot system which could be activated once autonomous cars get the go-ahead. *Teslamotors.com*

9 MONTHS

SONY PROJECT MORPHEUS

Sony's virtual reality headset has been pencilled in for early 2016. It'll work with the PlayStation 4 and will let you watch movies as well as games. *Sony.com*

Samsung smartwatch
The rumour mill is whispering that Samsung is considering a smartwatch overhaul, with its first Apple Watch-beating device set to launch before Christmas. *Samsung.com*

Dyson batteries
It 'fixed' vacuum cleaners and fans: now Dyson is doing batteries. It's put $15m into a company that claims to offer double the life of the best battery tech available. *Dyson.com*

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1

2
$45.17
The heat will come on in 1 hour, and will raise the temperature from approximately 66 °F to 68 °F

3

4

5

6

APPLIANCES OF SCIENCE

1 SEARCH AND RESCUE

If you're always losing the TV remote, your keys or wallet, then Bluetooth tags can help you find them in a hurry. These Pixie tags create a location network, triangulating off one another, to give your phone a precise location for each tag. It uses this data to superimpose an image of the tag onto your smartphone's camera view, so you can easily scan your home to find the elusive object.

Pixie Tags
$39.95 (£26.48) for four, getpixie.com

2 WHAT A SCORCHER

Nobody likes getting a heating bill through the door, but this new internet-connected thermostat could take the sting out of those letters. Thermoneystat shows you what you're spending in dollars (a UK version is in the works). You can even tell it a monthly budget. By looking at your allowance and your habits, this smart heating device could help you get a better handle on your bills.

Thermoneystat
Price TBC, thatmakesyoubetter.com

3 DO THE ROBOT

It's only a matter of time before the robots start taking all our jobs (there's already a robot journalist). So the only thing left to do is to become the person making the darned things. Q.bo is a simple build-it-yourself 'bot that will teach you about robotics. The platform is open source to encourage owners to hack and modify the robot, and come up with their own artificial intelligence systems.

Q.bo
From €755 (£544), thecorpora.com

4 POWERED UP

Most new Android smartphones include an option to charge wirelessly. These chargers usually look like small mats and create small magnetic fields that transmit energy to your phone. Ikea has had the bright idea to start incorporating these mats into their furniture so you can simply drop your phone onto them to start charging. The range will be out later this year and includes this adjustable lamp.

David Wahl Ikea Lamp
Price TBC, ikea.com

5 TIME, GENTLEMEN

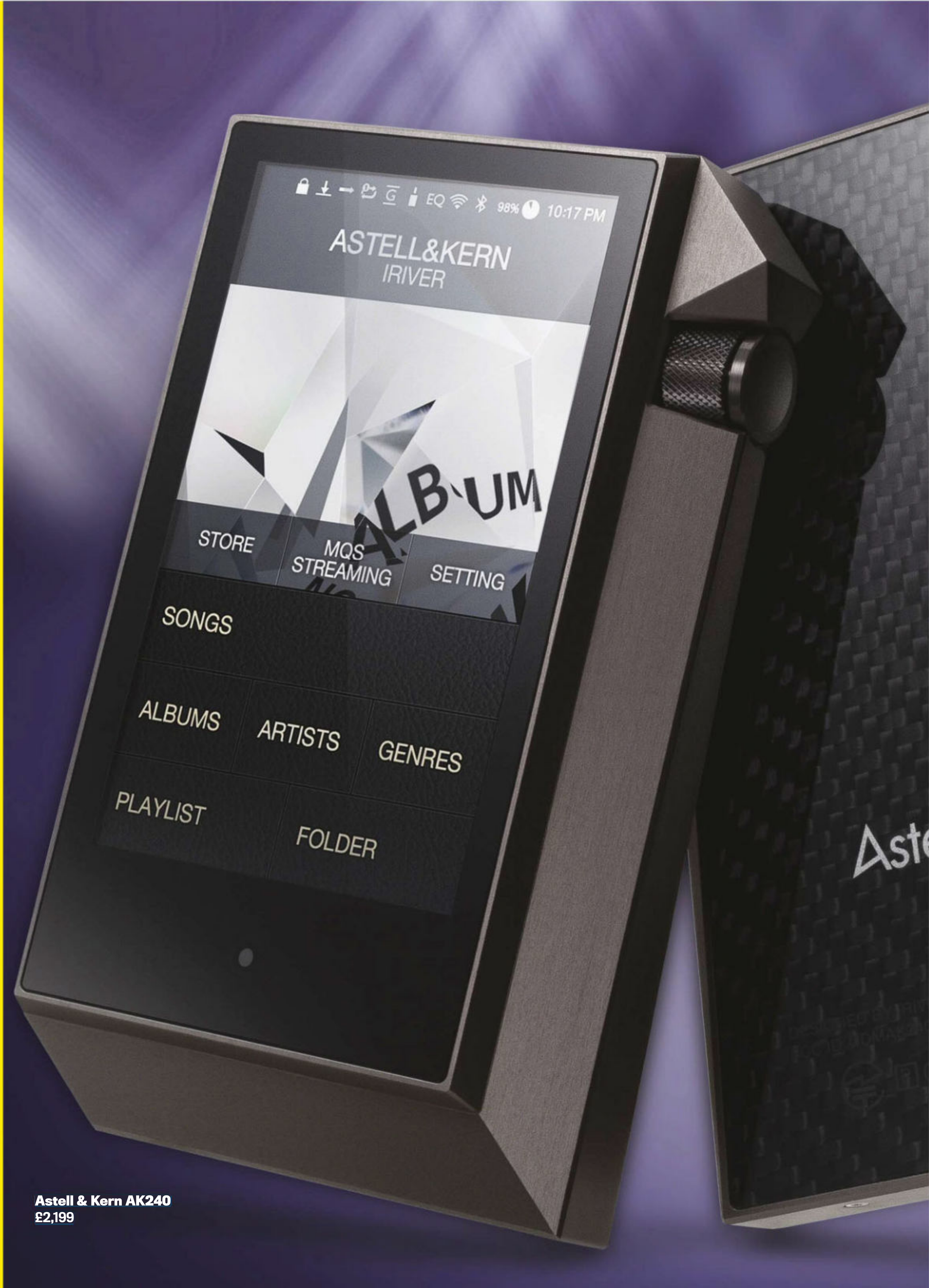
If your smartphone does too much for your liking, then the Runcible might be perfect for you. It is the world's first circular, wooden smartphone and is made for those hoping for a quieter life. It comes with a browser, maps and a compass, but not much else. The idea is to remove the urge to peek at your social media feeds. The creators say it'll be upgradeable, so it might be the only phone you'll ever need.

Runcible
Price TBC, mono.hm

6 NIFTY NANOGRID

Okay, so you won't see us camping too often, but this is the kind of light we'd take with us if we did. This palm-sized, battery-powered light can run for three days straight, or hook two or more torches together to illuminate your campsite for 22 hours. Once you're bathed in light, you can even use the device's built-in battery to charge up your phone or GoPro – now that's what we call camping.

BioLite NanoGrid
$99.95 (£66.40), biolitestove.com



Astell & Kern AK240
£2,199

ULTIMATE TEST

BEYOND THE IPOD

Daniel Bennett finds out if the new high-resolution audio players really do sound much better

THE IPOD HAS a lot to answer for. It sold us all on the MP3, and in the 14 years since its inception it's all but killed the CD. This wasn't such a bad thing, but somewhere along the way we stopped caring about the quality of our music. Whether we were chasing faster downloads or squeezing ever more albums onto our personal media players (iPods or otherwise), digital music became more compressed, with the audio quality diminishing along the way. That might all be about to change. Weary of the low-resolution MP3s typically sold by the likes of Google Play Music and iTunes, the music industry has started to fight back. Jay Z has just bought Tidal, which is a new streaming service dedicated to high-resolution audio. And then there's Neil Young, the Rock and Roll Hall of Fame inductee, who is launching Pono in the UK this month. This music store and handheld media player is all about high-resolution albums. Young and other musicians want their music to sound the way they want it to.

PLUGGING IN

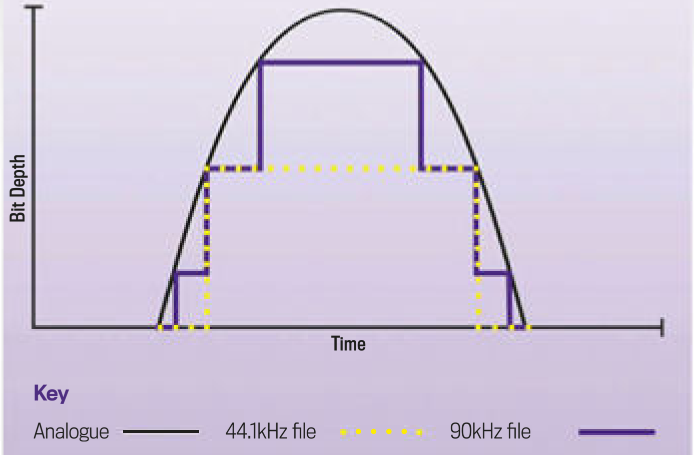
From the front, the triangular Pono looks rather like a simplified iPod, but thankfully it sounds

Rock legend Neil Young's Pono has its own PonoMusic store, where users can download high-resolution music. Pono claims to be the "next best thing to live music"

WHAT IS HIGH-RES AUDIO?

SOUND IS ANALOGUE, and it takes the shape of waves. Before CDs, this wasn't a problem since the primary medium for storing and selling music, tapes and vinyl was also analogue. Unfortunately, our current favoured method of storing music, the digital file, is inherently flawed. Digital information is recorded as a binary series of 1s and 0s – on and off. This means it can make an approximation of a wave, but it never truly records it (see graph). It's a bit like trying to build a circle with only flat Lego bricks. A high-resolution audio file does the best job it can by storing as much information as possible, which is why a high-res audio track can be over 10 times larger than an MP3. Meanwhile, a high-resolution media player's job is to decode that information and translate it back into an analogue wave as faithfully as possible.

SAMPLING A SOUND FILE



This graph demonstrates how a digital file recreates an analogue sound wave. The higher frequency 90kHz file is a better representation of the orginal analogue sound produced during recording than the 44.1kHz file.

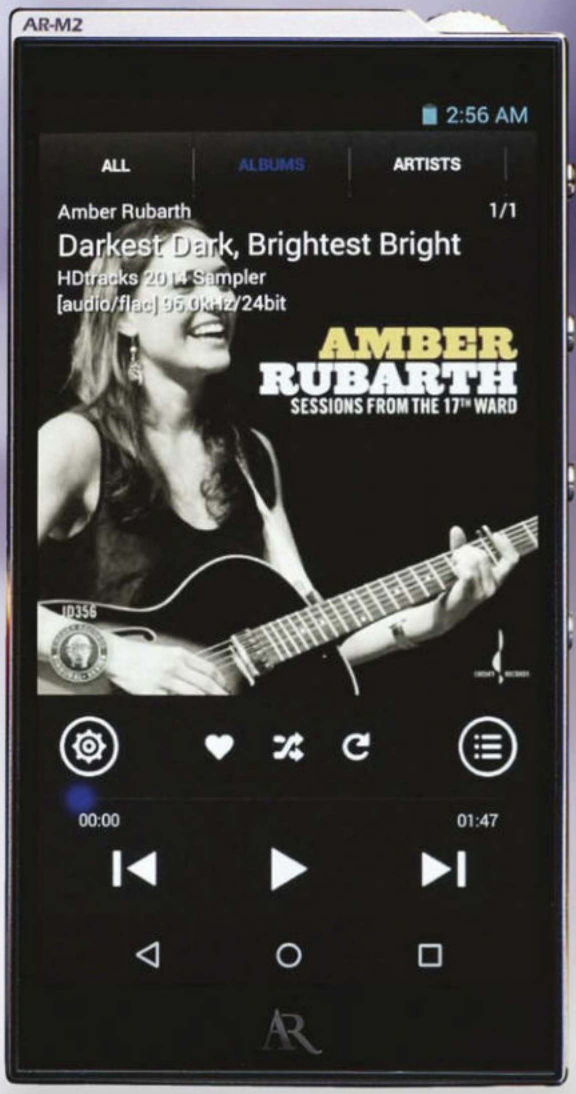
Pono
From $399 (£270)

➔ nothing like it. When we listened to it in a noisy hall at the CES tech convention in Las Vegas, a remastered copy of John Coltrane's live version of 'My Favorite Things' (192kHz/24-bit) came to life. For an instant it felt like a stage had popped up in front of us and the bustling crowds of the show had fallen away. Well, until we looked over our shoulder to find an eager queue of listeners taking shape behind us.

That experience in January left us hankering for more, but sadly there were no samples of the Pono available for us to borrow. Not to be beaten, on our return to the UK we sought out the best new high-resolution media players money can buy: Acoustic Research's M2 and Astell & Kern's AK240. At £900 and £2,199 respectively, these aren't devices you purchase on a whim. But if you did invest, both are high-tech enough to replace your whole music system.

Everything you need to know about the AK240 is in its price. You're absolutely getting what you pay for. Out of the box it's probably the best-looking media

PHOTO: GETTY



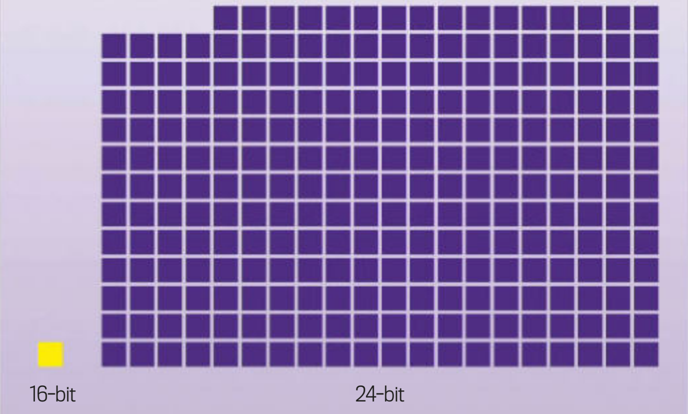
Acoustic Research M2
£900

AUDIO FILES EXPLAINED

HIGH-RESOLUTION AUDIO can be recorded in dozens of file types, but Apple Lossless and FLAC are the two most common. The type you choose will be dictated by what you want to play it on, but for audio quality there are two pieces of data you need to look for.

The first is the frequency or the sample rate. This relates to how many times per second the music is being digitally captured. To go back to the Lego analogy (see p84), the more bricks you've got the more convincing your circle is. The sample rate is usually measured in kHz. A CD comes in at 44.1kHz, or 44,100 slices per second. The second piece of information is the bit depth. At each point where information is captured (where the digital line meets the analogue line in the graph on p84), more or less information about the audio can be stored. So 16-bit audio means that 65,536 possible sound levels can be recorded, whereas 24-bit can record 16,777,216 sound levels – 256 times the possible resolution. The bigger the sample rate and the bit depth, the larger the file will be. When buying high-res music, accept a sample rate no lower than 44.1kHz, and a bit depth no lower than 16-bit. Pono is working to offer most of its library at 192kHz/24-bit.

16-BIT VERSUS 24-BIT



■ = 65,536 possible audio levels to capture the sound

player available on the market. It feels just the right weight, while the sleek gunmetal finish and carbon fibre plating suggest it's built to last – and it had better at that price. As you'd expect, listening to something like The Beatles' *White Album* at 192kHz/24-bit on a pair of Oppo PM-1 headphones (again, some of the best that money can buy), the device is hard to fault, even compared to a dedicated hi-fi setup. But it's actually with some poor-quality files – like an MP3 from the latest Run The Jewels album – where the AK240 impressed most, even when played through some clunky headphones. It's one of the few audiophile devices that doesn't seem too snobby about what you're playing or what equipment you're using and simply makes the whole listening experience that much better.

At less than half the price, the M2 certainly isn't half the product. Okay, it might not be as nicely put together and we do have some reservations about its size. But its engineers tell us it has to be that big just to fit all of its technology and components inside. Again, it'll play every music file worth having, and is powerful enough to drive most headphones, even the bigger headphones you use at home that tend to require dedicated amplifiers. A favourite album, Grizzly Bear's *Shields*, was an absolute treat to listen to, revealing fresh nuances along the way. Of course that's bound to happen with £900 worth of equipment, but it's the scope of the sound that impressed us. By giving the bass and treble more texture, it felt like we'd suddenly taken off the blinders and were able to see the whole picture.

Whether it's a £270 Pono, or devices that cost three or seven times as much, it's hard to see how anyone would regret switching to high-res audio. To a newcomer, the gains between each device would be marginal, but once high-resolution audio sucks you in it's easy to see why people start to climb the fidelity ladder. And with streaming services like Tidal, and more artists increasingly selling their music on their own sites at the highest quality, there's little excuse not to listen to your music exactly how it was meant to be heard. ■

THE AGE OF THINGS

BY GILES SPARROW

Written history only stretches back a few thousand years, so scientists had to come up with techniques to help them establish the ages of fossils, rocks and remains from ancient times

FOR ARCHAEOLOGISTS, palaeontologists and geologists, working out the age of ancient materials is a crucial step to understanding their significance. Whether it's an ancient housing timber or a fossilised dinosaur bone, having an idea of its age is key to working out how an object fits in with its surroundings.

Working out the age of things is far from simple. For some relatively recent objects and structures, we may be able to tie them to written records. But our written history is a blink of an eye in comparison to Earth's long timespan. As a result, scientists studying the past must use a wide range of different techniques to date objects. These may provide a relative context by identifying which materials are older or more recent than others. Alternatively, they could provide an absolute date, either by combining archaeological information with historical records, or by using techniques that are rooted as much in the physics laboratory as they are in the dig site or library.

The most obvious means of dating objects is to attempt to put them in a context provided by historical documents. This was the thinking that sent archaeologists to the Near East in the 18th and 19th Centuries, hoping to dig up finds linked to the Bible and other ancient chronicles.

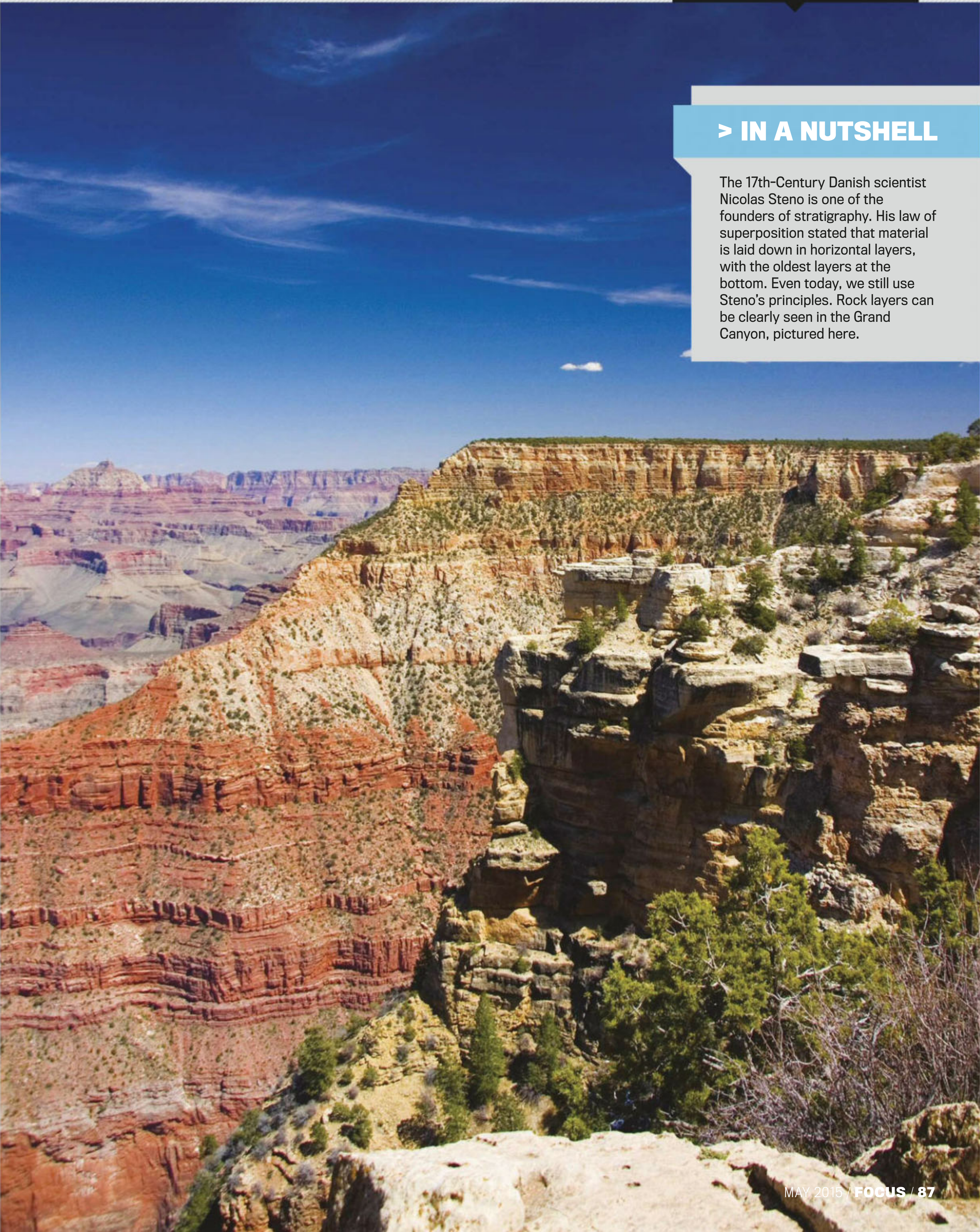
MATCH IT UP

One way of calibrating records from different civilisations using different calendar systems is to look for matches between recorded events – for example major military clashes, often involving specific rulers, that may have been noted by both sides. Astronomical phenomena can be even more useful. Chroniclers often recorded spectacular solar eclipses, and these take place according to the inexorable laws of celestial mechanics. The precise dates of past eclipses can then be worked out in our modern calendar, giving precious fixed markers for ancient chronology. As early as 1867, British politician and archaeologist Sir Henry Rawlinson pinpointed an eclipse recorded in ancient Babylonian writings to 15 June 763BC. This date is now generally considered to anchor an entire strand of history dating back as far as 910BC, affecting not just Mesopotamia, but also Egypt and further afield.

Archaeologist Sir Henry Rawlinson used records of celestial events to figure out historic dates

But there are major problems with relying on written chronicles: only a limited number of events were considered worth recording, so it's rare for those to relate to specific archaeological remains. And even if they do, archaeologists have often discovered the hard way that chroniclers are not always accurate. A long-standing problem in Biblical archaeology, for example, is the lack of physical evidence for

PHOTO: SCIENCE PHOTO LIBRARY, ROBERT HARDING



> IN A NUTSHELL

The 17th-Century Danish scientist Nicolas Steno is one of the founders of stratigraphy. His law of superposition stated that material is laid down in horizontal layers, with the oldest layers at the bottom. Even today, we still use Steno's principles. Rock layers can be clearly seen in the Grand Canyon, pictured here.

the 'Golden Age' of trade and construction that the Bible says happened in the Kingdom of Israel under King Solomon around 950BC. Spectacular finds led by analysis of historical records, such as the 2012 discovery of Richard III's remains buried beneath a Leicester car park, are few and far between.

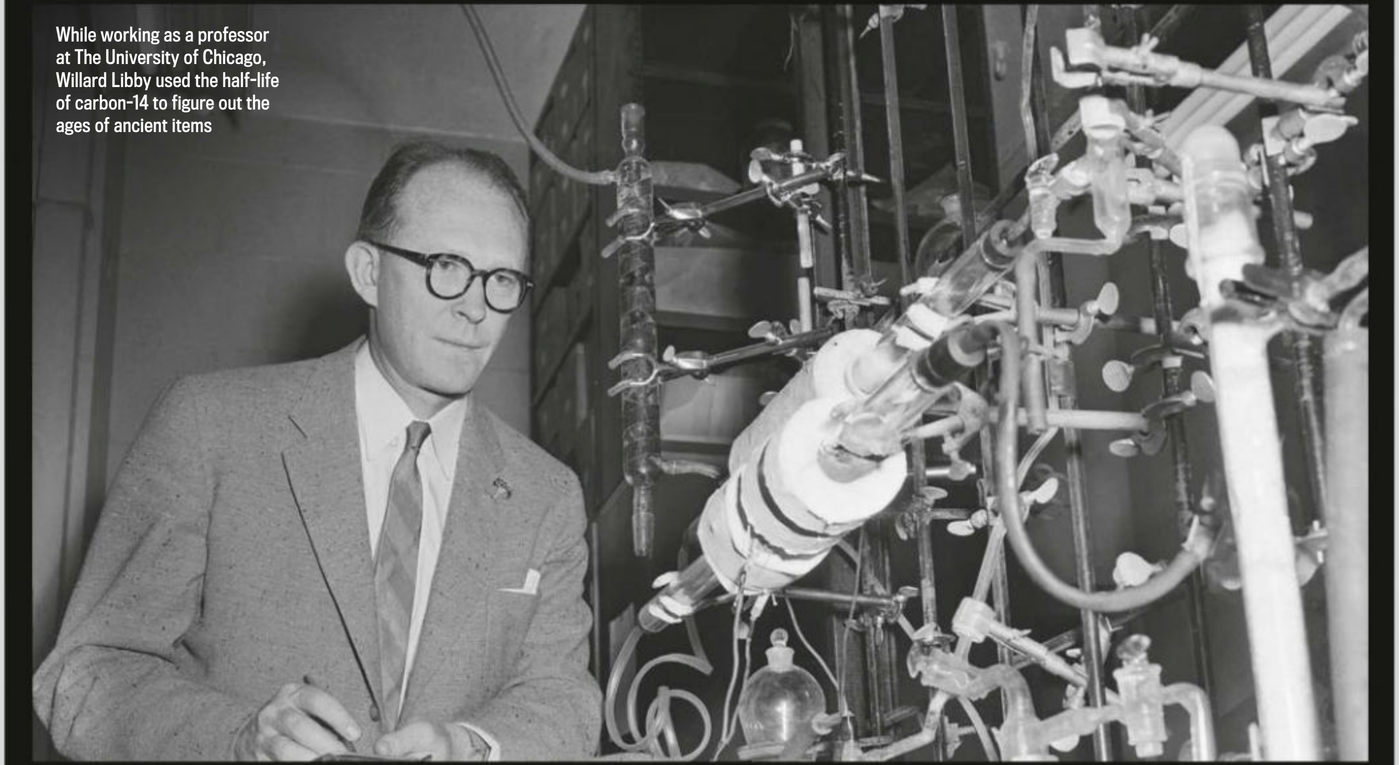
Archaeologists tend to avoid over-dependence on ancient historians. Instead, they rely on principles and techniques shared with palaeontology and geology. The most fundamental of these, written down by Danish scientist Nicolas Steno and published in 1669, forms the basis of stratigraphy.

Steno's law of superposition states simply that materials are deposited in horizontal layers, with the lowermost layers formed first. Barring any later disturbance, more recent material will always lie on top of older material. His principles of original horizontality and lateral continuity are most significant in geology – they point out that strata (layered deposits within rock) initially form in horizontal layers, and will spread out widely over a surface unless some obstacle blocks their way. Finally, the principle of cross-cutting relationships states that features cutting across or otherwise disrupting a stratum must have formed after it.

For geologists and palaeontologists, Steno's principles help reveal the sequence of different rock layers and the fossil remains that may be embedded within them. For archaeologists, the same basic rules of stratigraphy can show the sequence in which different buildings or other human-related artefacts have built up over time. William Cunnington, a merchant and self-educated antiquarian, was the first to apply stratigraphy in this way from the late 18th Century, while studying prehistoric monuments in the English county of Wiltshire where he lived and worked.

THE KEY EXPERIMENT

Willard Libby thought that carbon-14 was present in all living things. After proving this to be correct, he realised that the isotope could help establish the age of relics


While working as a professor at The University of Chicago, Willard Libby used the half-life of carbon-14 to figure out the ages of ancient items

IN 1939, WILLARD Libby led an investigation at UC Berkeley looking at whether any of the elements common to organic matter might have useful radioactive isotopes that could be used in medical research. Using highly sensitive Geiger counters that he had developed, Libby established that carbon-14 (C-14) was far more stable than previously thought, with a half-life of 5,730 years. Working with colleagues, he subsequently pinpointed its likely origin to cosmic rays interacting with atmospheric nitrogen. He formed the idea that C-14 might therefore be a natural component of all living organisms. The intervention of WWII meant that he was unable to pursue these ideas until 1945. Later, at The University of Chicago, he first established that his thesis was correct by comparing the radioactivity of sewage methane with that extracted from refined petroleum. He then floated the idea that radiocarbon could be used for dating organic remains. In 1949, Libby and his colleague James Arnold tested the technique on wood from the tombs of two Egyptian pharaohs. They measured the current rate of radioactivity in their samples and delivered dates of around 2700BC, which matched up with those established by other methods. Libby was ultimately awarded the 1960 Nobel Prize for chemistry for this work.

PHOTO: CORBIS, SCIENCE PHOTO LIBRARY X2, GETTY X2, SCIENCE & SOCIETY

Some archaeological finds come with their own dating information conveniently attached. Most plentiful of these are coins, which frequently name and depict the ruler who authorised their issue. Inscribed stones and other artefacts are rarer, but can be still more informative. But even then, the dates they provide have their limitations. Barring exceptional circumstances, artefacts can remain in use for long periods after their manufacture, so a coin found in an archaeological deposit only provides an 'earliest possible' date for an event.

TOP OF THE POTS

In the late 19th Century, English archaeologist WM Flinders Petrie made a huge advance in the study of historic objects. Through careful investigation of finds from a range of sites – at first in Egypt and later across the Near East – he identified different pottery styles. He then worked out the most likely sequence in which they had been introduced, become popular and fallen out of use. Pottery proved to be the ideal raw material for a new dating technique called 'seriation' because it has been cheap and widespread since the beginning of human civilisation. It is quite fragile, and is therefore more likely than precious coins to be broken and discarded shortly after manufacture, yet its individual fragments preserve well after disposal.

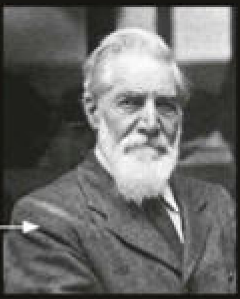
Petrie used the seriation technique for dating his excavations. He used simple strips of paper to record the range and frequency of pottery styles at certain sites, and shuffled them into what seemed the most economical, logical order. Throughout the later 20th Century, however, archaeologists applied increasingly rigorous approaches to seriation, including the 'Harris matrix'. This is a diagrammatic chart of finds and their stratigraphic contexts that was developed by Bermudian archaeologist Edward C Harris in the 1970s. They also used Bayesian statistics, which is a very powerful method for analysing the evidence for different hypotheses. This was invented by English philosopher Thomas Bayes around 1760, but only started to be applied in archaeology from the 1980s.

Most archaeological finds, however, come with no such convenient dating evidence. As

CAST OF CHARACTERS

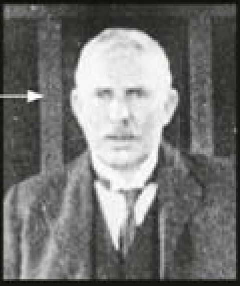
Five talented scientists who helped us establish the age of things

Nicolas Steno
(1638-1686)
Steno was a Danish Catholic priest, and later bishop, with a fascination for the natural world. He laid down the laws of stratigraphy and made one of the first detailed studies of fossils, but wrongly concluded that they formed within the ground. He was the first person to identify the heart as a muscle.



WM Flinders Petrie
(1853-1942)
Petrie was fascinated by archaeology from a young age. He surveyed prehistoric sites as a teenager, before travelling to Egypt and making the first rigorous study of the Giza pyramids. Alarmed by the destruction of ancient monuments, he dedicated the rest of his career to preserving and excavating sites across Egypt and Palestine.

AE Douglass
(1867-1962)
US astronomer Douglass helped Percival Lowell establish his famous observatory at Flagstaff, Arizona, before splitting with him over Lowell's belief of canals existing on Mars. He first investigated tree rings as a means of mapping past cycles of solar activity, but realised they could provide a powerful dating tool.

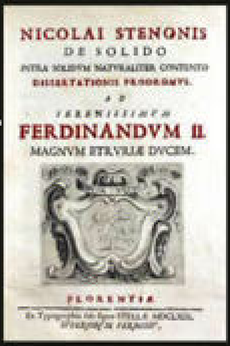


Ernest Rutherford
(1871-1937)
New Zealand-born Rutherford was a physicist who conducted research into radio waves and radioactivity. Working in Montreal, Manchester and Cambridge, he discovered the existence of the atomic nucleus, identified the three main types of radioactive decay and mapped out the 'decay series' of important radioactive isotopes.

Willard Libby
(1908-1980)
Colorado-born chemist Libby spent his early career at The University of California, Berkeley. Here, he developed new forms of Geiger counter and identified intriguing properties of C-14. He became a professor at The University of Chicago, where he led a team that made radiocarbon dating a reality.

TIMELINE

Five vital steps that helped us to start determining the ages of human artefacts, fossils and rocks


NICOLAI STENONIS

DE SOLIDO

FERDINANDVM II

MAGNVM ETRVRIAE DVCEM.

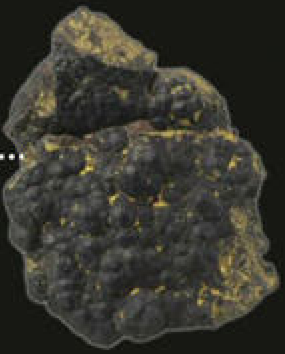
1669

Nicolas Steno publishes his *Dissertationis Prodromus* or *Preliminary Discourse*, outlining principles of stratigraphy. These are still widely applied across the sciences of geology, palaeontology and archaeology.

1898

While excavating the site of Diospolis Parva in Egypt, WM Flinders Petrie develops the ideas of pottery seriation in order to establish the relative dates of structures with no linking stratigraphy.

1907

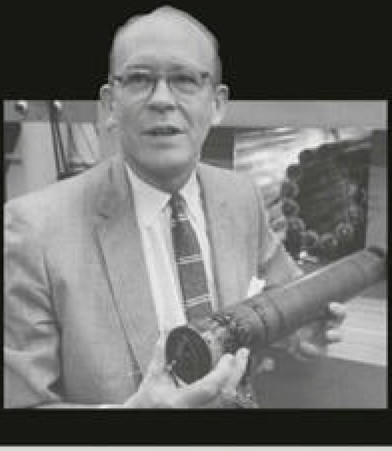


Bertram Boltwood identifies lead as the end-product in the radioactive decay of uranium, and subsequently uses the proportion of lead in uranium ores as a means of dating rocks.

1919

AE Douglass applies the techniques of tree ring dating to establish the relative dates of several Native American sites across the American Southwest – the first archaeological application of his ideas about 'dendrochronology'.

1949



Willard Libby publishes the first tests of his radiocarbon dating technique, opening the door for a revolution in the dating of archaeological remains.

PHOTO: GETTY X3, ISTOCK, SCIENCE PHOTO LIBRARY

scientists have found on many occasions, assumptions about the relative sequence of events in evolution or geology can turn out to be wildly inaccurate. Fortunately, two discoveries in the 20th Century paved the way for a new range of dating techniques that are widely used today.

RINGING THE CHANGES

The first of these techniques was surprisingly simple – the variability of tree growth rings. Each year a tree is alive, its trunk lays down a distinct, concentric ring. Around 1906, US astronomer AE Douglass showed for the first time that the thickness of these rings depends on growing conditions for that particular year. He developed this principle into the highly accurate method of dating known as dendrochronology. The pattern of growth rings in any piece of timber from a specific region acts rather like a barcode revealing exactly when it was alive. By comparing numerous timbers of overlapping ages, it is possible to count back through the years from timbers with a known age. Of course, this technique can only be applied to wood, but becomes more powerful when used in conjunction with another 20th Century breakthrough – 'radiometric' dating.

While investigating the behaviour of radioactive materials at Canada's McGill University between 1900 and 1906, New Zealand-born physicist Ernest Rutherford discovered the statistical property known as 'half-life'. For a sample of any particular radioactive material, the time taken for half of the atoms or 'isotopes' within it to decay is constant. In other words, after this period, half the original material will remain. After two, a quarter would remain, and so on.

Rutherford thought that radioactive decay could be used as a means of dating rocks. Following his suggestion, US physicist Bertram Boltwood realised in 1907 that uranium's slow decay into stable lead would gradually increase the amount of lead within uranium ores. Using this idea, he dated a variety of rocks to between 400 million and 2.2 billion years old, vastly extending the known age of the Earth.

Natural radioactive decay happens on a huge range of timescales, from billions of years to fractions of a second. Most decay series used for radiometric dating are on the slowest of these timescales. Uranium-lead dating, for example, uses two different decay series with half-lives of 4.47 billion and 704 million years. Such techniques are less accurate for recent materials because the decay of any radioactive isotope is unpredictable over short periods of time – it can be hard to tell the gradual decline of the 'decay curve' from random variations.

A scientist removes a sample from a piece of bone for carbon dating

IT'S A DATE

The best-known dating method of all allows us to date more recent materials to a high degree of accuracy – and what's more, it works directly for organic remains rather than rocks and minerals that may be associated with them. The technique relies on the fact that small quantities of a radioactive isotope called carbon-14 (so-called 'radiocarbon') are continuously created by cosmic rays high in Earth's atmosphere, and subsequently absorbed into the bodies of all living organisms. Carbon-14 (C-14) decays into nitrogen with a half-life of 5,730 years. While a plant or an animal is alive, its internal proportion of C-14 remains the same as that in the atmosphere. As soon as it dies, exchange with the environment stops and the C-14 begins to diminish.

Radiocarbon dating was invented in the 1940s by US chemist Willard Libby and has become a major tool in the archaeologist's armoury, as it's useful for dating human and animal remains as well as timber. The C-14 present in the material can either be estimated by measuring its radioactivity with a Geiger counter, or more accurately measured directly by breaking the sample down in a mass spectrometer.

Radiocarbon dating is not without limitations. C-14's relatively short half-life means that for remains more than about 50,000 years old, dwindling quantities make precise dating increasingly inaccurate. Even more significantly, the proportion of atmospheric C-14 can vary over time, depending on levels of cosmic-ray activity. Samples of different ages can therefore begin the process of decay from different levels. This problem was first identified by Dutch physicist Hessel de Vries in the late 1950s, and scientists have since dedicated a great deal of effort to developing a 'calibration curve' that estimates atmospheric C-14 over the past 50,000 years. They do this mostly by comparing radiocarbon dates with those derived from tree rings and other evidence, using computer models and Bayesian statistics to analyse the most likely scenarios.

The search for more precise and versatile dating techniques for all kinds of materials is an ongoing challenge, but it must be faced in order to improve our understanding of the past – for our planet, prehistoric life and ourselves. ■

GILES SPARROW is a science writer and author. His latest book is *Mars*

BBC To find out more about fossils and to watch clips, visit bbc.co.uk/nature/fossils

NEED TO KNOW

A glossary of terms used in the dating of ancient artefacts

1 COSMIC RAY

Cosmic rays are not a form of radiation. They are high-speed particles released by the Sun and even more violent and distant celestial objects, and enter Earth's upper atmosphere from space. Here, they may interact with gas atoms, breaking down into lower-energy particles and triggering the transformation of nitrogen into carbon-14.

2 HALF-LIFE

Radioactive decay is an unpredictable process, but when enough radioactive isotopes are present, statistical laws can be applied: the half-life of any specific isotope is the average time that it will take for half of a sample to undergo decay. Depending on the isotope in question, half-lives can vary from billions of years to fractions of a second.

3 ISOTOPE

Isotopes are atoms of the same element with different masses. These arise from variations in the number of neutrons in each atomic nucleus. An element's isotopes have identical chemistry, but heavier isotopes can have unstable nuclei and will undergo radioactive decay in order to reach a stable form.

4 MASS SPECTROMETER

A mass spectrometer breaks down a small sample of material into its component atoms. It separates them using electromagnetic fields and measures their relative proportions. Mass spectrometers are useful for many types of radiometric dating since they allow the precise ratios of isotopes in a material to be determined.

5 STRATIGRAPHY

Stratigraphy is the study of the patterns in which rock layers and other associated materials are laid down. It is the key to understanding the formation of rocks and archaeological deposits. For older rocks especially, determining the true stratification of a site involves not just the study of mineral layering, but also the way in which fossils have been laid down.

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PIC MONTH

Alice Roberts reveals some surprising health benefits of vegetables

Britain's Favourite Foods: Are They Good For You?

THANKS TO THE computerisation of supermarket tills, it's easier than ever to tot up how much we spend on different foods (over £400m on mushrooms every year, for example) and how much we consume (700,000 chickens a day). In this programme, BBC presenter Alice Roberts brings all that data together to look at the chemical and biological interactions between our dinners and us.

You're probably already aware that fruit and vegetables are rich in vitamin C, but do you know how to get more of other vitamins by preparing familiar foods in different ways? For example, mushrooms are rich in B vitamins, but it's possible to get vitamin D from them as well.

Alice is put on an exercise bike to test out a new theory that states milk is better at rehydrating you after activity than water or expensive sports drinks. "I don't much like cycling in an environment chamber at 30°C and 30 per cent humidity," says Alice. "But I bore it, in the name of science. And lost 800ml sweat in the process. More than once."

Some claims seem a little more tenuous. For example, can eating certain vegetables make you look younger, healthier or more attractive? And what about dairy products? "I was extremely pleased to discover some good news about cheese in the course of making the programme, as I feel that it's often such an unfairly maligned food," she says.

Certain foods are even thought to have intriguing psychological effects. Protein, for example, may affect our brain's decision-making process, which is something to bear in mind when you're wondering whether to gobble a Scotch egg before that important meeting.

Of all the experts in the programme, Dr Paul Kroon wins our Best Job Title competition with 'biochemist and apple expert'. But does an apple a day really keep the doctor away, or are we wasting our time by chomping our way through 17 million of them every day? Tune in this month to find out whether Dr Kroon ever actually manages to get close enough to the objects of his study to find out.

TIMANDRA HARKNESS

BBC TWO

Watch *Britain's Favourite Foods: Are They Good For You?* on BBC Two this April

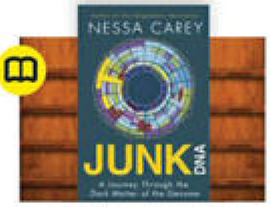
DON'T MISS!

Earthrise

In the mid-1960s, the Soviet space programme was beating NASA to the major hurdles, until Apollo 8 was launched... **p94**

Edinburgh International Science Festival

This year's festival is big on the brain, but covers everything culinary too. Foodies rejoice! **p97**



Junk DNA

Incredibly, 98 per cent of our DNA is classed as 'junk', but is it time it had a rebrand? **p98**

PHOTO: BBC

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WITH TIMANDRA HARKNESS

APRIL

End Of The World Night

Channel 4, dates and times TBC

"I THINK WE'RE going to have a bumpy ride through this century," says Astronomer Royal Martin Rees. From rising seas to falling stars, from the Four Horsemen of the Apocalypse to John Cusack (left) outrunning volcanoes in *2012*, we love to imagine our own demise. Join scientists, philosophers and Hollywood's finest for a night that could be your last.

19 APRIL

Mankind From Space

National Geographic, 8pm

America's 'Big Apple' from above

FOR A NEW perspective on our history, let's look down from space. Satellites reveal in ever increasing detail how we're shaping our world. In this documentary, CGI tells the story of one primate species that rose from hunting and gathering to create civilisations, and ultimately became the first of Earth's creatures to look back on itself on a planetary scale.

27 APRIL

Hacking The System

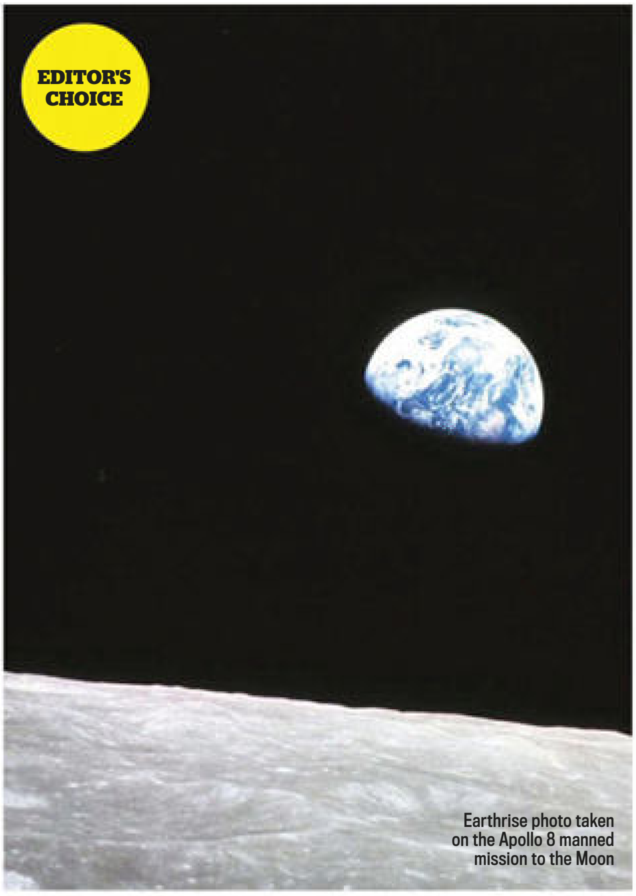
National Geographic, 11pm

EVER THOUGHT THERE must be a smarter way to open a bottle of beer, or to get somebody to come on a date? Brian Brushwood (left) claims that there is, and he can teach you how. Brushwood is an illusionist who appeared on *Scam School*, so don't blame us if the whole programme turns out to be a life hack to "get a series on National Geographic".

TIMANDRA HARKNESS is a stand-up comedian and a regular presenter on BBC Radio 4

PHOTO: PICSELECT.COM, NATIONAL GEOGRAPHIC CHANNEL, NASA X2

EDITOR'S CHOICE



Earthrise photo taken on the Apollo 8 manned mission to the Moon

12 APRIL

Earthrise: The First Lunar Voyage

Discovery, 8pm

IT'S EASY TO think that NASA's victory in the Space Race was inevitable. In the mid-1960s, however, things looked very different. The Soviet space programme had beaten the US to all the major milestones – Sputnik was the first artificial satellite, Yuri Gagarin the first man in space, Valentina Tereshkova the first woman…

The three astronauts of Apollo 8 were under pressure to train fast for the mission that would escape Earth's gravity altogether and go around the Moon. For the first time, human beings would be out of sight of the Earth, beyond radio contact. They would be embarking on an orbit that could, if things went wrong, leave them drifting forever in space.

This documentary uses footage from NASA and other sources, and includes interviews with those involved. In addition to the men in the capsule, we hear from those left behind: the ground crew, their wives and others.

Failure would have cost three lives, and also the last shreds of hope that the US could win the symbolic and technological race to the Moon. But success promised to turn NASA's fortunes around forever…

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LISTEN

BBC RADIO PROGRAMMES

WITH TIMANDRA HARKNESS

FROM **28** APRIL

ISIS vs IT

BBC World Service, various times

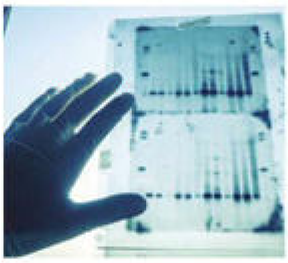
FOR A TERRORIST group that's trying to drag the Middle East back to medieval barbarity, ISIS – also known as Daesh – is a keen user of social media. Dominic Casciani looks at efforts to counter its influence, and asks who should police ideas in the online world.

APRIL

Forensics In Crisis

BBC Radio 4, dates and times TBC

DNA FINGERPRINTING WAS invented in the UK, but since the world-leading forensic science service was privatised and its budgets cut, problems have emerged. In this three-part series, science journalist Linda Geddes dissects the evidence that the whole system faces a crisis.



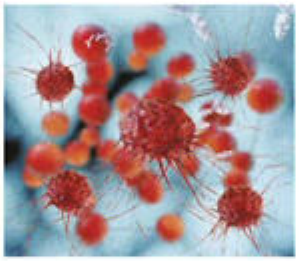
DNA analysis is a vital part of forensics

17 APRIL

Is Cancer Money Well Spent?

BBC Radio 4, 8pm

IT'S HARD TO think of a better use of money than to save the lives of cancer sufferers. But is the NHS spending its money wisely? Specialised drugs that may only be effective in a few patients cost billions of pounds per year, but they are not the only treatments that work.



Cancer: a costly illness

8 & **19** APRIL

The Forum: Magnetism

BBC World Service, various times

BRIDGET KENDALL HOSTS another meeting of minds, recorded in front of a live audience. This one, on the theme of magnetism, features astrophysicist Katherine Freese among the panellists.

PODCAST

Self Orbits CERN

bbc.co.uk/podcasts/series/selforbitscern

JOURNALIST WILL SELF (pictured) uses a 50km walking tour of the CERN facility to find out what they do there and why he should care. Over five episodes, he gropes towards an understanding of particle physics and attempts to replace his bafflement with wonder.

PHOTO: ISTOCK X3, CHRIS SCOTT, SCIENCE MUSEUM

TOUCH

SMARTPHONE & TABLET APPS

WITH KATE RUSSELL

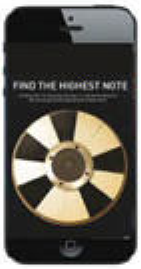
NASA Visualization Explorer

iOS 5.1 or later, iPad/iPhone/iPod Touch, NASA, free

FOR A TRULY mind-expanding experience, take a browse through a visual collection of hundreds of stories coming out of NASA's space research. This free app is updated with new content twice a week and neatly packages up pretty much everything we have learned about the Solar System and beyond. Content is mainly sourced from NASA's Scientific Visualization Studio, Earth Observatory and Science @NASA, and includes photographs, audio and video descriptions, animations and text stories, plus links for digging deeper.

Sound Uncovered

iOS 6.0 or later, iPad, Exploratorium, free



HAVE YOU SEEN the television advert that says 'sounds like a Golf'? Far from being a concept dreamt up by some clever executive, scientists have known for a long time what a powerful effect sound can have. In fact, an awful lot of engineering bucks go into making modern cars 'sound' more solid to help loosen a buyer's wallet. In the interactive *Sound Uncovered* app, you'll learn all about acoustic phenomena, auditory illusions and sound-processing techniques. The free app includes images, virtual experiments, videos and webcasts that teach you all about how sound works. You'll even find out why the sound of gum being chewed drives some people up the wall.

AuroraWatch UK

All mobiles, Lancaster University, free

THE AURORA BOREALIS is usually seen in the far north of Europe. But when conditions are just right, it is sometimes possible for people in the UK to be treated to a show. The natural phenomenon is caused by electrically charged particles entering Earth's atmosphere. When the Sun throws out a lot of these particles during a coronal mass ejection, you might catch a glimpse of the lights in UK skies about three days later. *AuroraWatchUK* isn't exactly an app, but their website explains how to sign up for a text message alert. You'll then get this sent to your phone when there's the best chance of catching nature's light show where you live.

KATE RUSSELL is a technology journalist and BBC *Click* presenter

VISIT

EVENTS & EXHIBITIONS

WITH JHENI OSMAN

15-16 APRIL

The Engineering Simulation Show

The Roundhouse, Derby, http://bit.ly/1Gp2oEt

ENGINEERS DON'T JUST design bridges and jumbo jets. This show reveals the diverse range of engineering roles out there, whether you're interested in F1 cars or chocolate.

16 APRIL

The Science Of Breaking Bad

Royal Institution, London, 7pm-8:30pm, £12, members free, rigb.org

CHEMIST DAVE SMITH and psychologist Julian Boon delve into the science of *Breaking Bad* in this talk chaired by Claudia Hammond.

UNTIL 17 APRIL

Light Works

St Andrew's Square, Edinburgh, www.rps.org

JOURNEY THROUGH THE electromagnetic spectrum and find out how each kind of 'light' is used in our daily lives.

18 APRIL

Harrison Decoded

National Maritime Museum, London, 10:30am-4:30pm, £45, advance booking recommended, rmg.co.uk

AT THIS WORKSHOP, join discussions, go behind the scenes and find out more about esteemed clockmaker John Harrison.

18 APRIL

A Violence Of Gifts

St David's Hall, Cardiff, 7:30pm, £10-£32, stdavidshallcardiff.co.uk

JUST BEFORE THE Large Hadron Collider is switched back on, attend the world premiere of new music inspired by the Big Bang.

22 & 24 APRIL

Three Tales

Science Museum, London, 7:30pm, £22, sciencemuseum.org.uk

A LIVE ORCHESTRA supports a documentary about three events in the 20th Century that show how tech grew to dominate society.

Making a salad is more complicated than you'd think...

EDITOR'S CHOICE

4-19 APRIL

Edinburgh International Science Festival

Various venues, Edinburgh, free, sciencefestival.co.uk

THIS YEAR'S FESTIVAL is big on the brain, with talks exploring the meaning of consciousness, the search for the soul, and whether there's a difference between grey matter in men and women. Meanwhile, BBC presenter Adam Rutherford discusses artificial intelligence, as portrayed in the recent movie *Ex Machina*. If you prefer fantasy to sci-fi, comedian Helen Keen investigates the science behind *Game Of Thrones*' fire-breathing dragons, royal interbreeding and skull crushing. And science talks for foodies tackle everything culinary, from brewing coffee, beer and spirits to the cutting-edge cookery techniques of molecular gastronomy.

25-26 APRIL

Maker Faire

Life Science Centre, Newcastle, family £24.10, makerfaireuk.com

CRAFTERS, CODERS, BACKYARD inventors and DIYers – this Maker Faire is your chance to show what you're made of.

FROM 1 MAY

Home

Science Gallery, Dublin, free, dublin.sciencegallery.com

HEALTH SENSORS, VERTICAL farms and homes beyond Earth are the focus of this exhibition on the future of all things domestic.

1 MAY

Dino Snores For Grown-Ups

Natural History Museum, London, £180, nhm.ac.uk

WE'RE NOT PROMISING live snoring dinosaurs. But we *are* promising a night you'll never forget – with music, science, art, cinema, a three-course dinner and breakfast.

READ

THE LATEST SCIENCE BOOKS REVIEWED

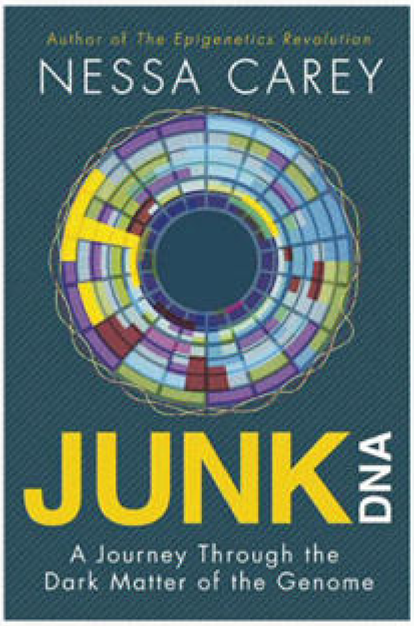
H Hardback P Paperback

Junk DNA:

A Journey Through The Dark Matter Of The Genome

Nessa Carey

Icon Books H £18.99


Author of The Epigenetics Revolution
NESSA CAREY
JUNK DNA
A Journey Through the Dark Matter of the Genome

THE 'DARK MATTER' at the heart of this book is a common fallacy: that as much as 98 per cent of our genetic material is 'junk' because it doesn't code for functioning proteins. So what's it doing there?

Author Nessa Carey quickly puts this fallacy to bed and gets on with her real objective: a journey through the complex world of genetics. The trouble is, that journey is rather too straight. At times, *Junk DNA* reads rather like a textbook. Most of the chapters include long spells of painstaking explanations punctuated with some hit-and-miss humour and sometimes obscure, occasionally baffling, cultural references.

Genetics is fiendishly complex. "The astonishing triumph is that we understand any of it," writes Carey. Her explanations are decent, but they are littered with many, many analogies, some stranger than others. One can't blame the author entirely: genetics, with its machinations and variations, is chock-full of processes so intricate that many scientists and writers have resorted to analogy to explain. Carey's anaologies are supported by functional but uninspiring diagrams straight out of a PowerPoint presentation.

But the real miss here is the lack of characters and story. While genetics is complicated, it's full of drama. There are warring scientists, billion-dollar businesses, tragic patients, left-field hypotheses and long-held beliefs (including the titular junk DNA). The book dances around them all but never really brings them to the fore. Diseases are named, but actual patients or scientists lie anonymous on the fringes of each subject. "DNA in a test tube is pretty boring," writes Carey. It can be on the page, too. While I admire Carey for making the genetics itself the star of the show, with a subject this complex and jargon-filled, relatable characters are sorely missed.

"Genetics is full of warring scientists, billion-dollar businesses, tragic patients and long-held beliefs"

There is some fascinating material here, including the relics of ancient virus invaders left in our DNA. The book also takes a look at the 'junk' sequences far away from a gene that can still have a profound effect and the condition that makes you age prematurely. There is a tragic legacy of genetic diseases, and people's fates are set by the base pairs of their DNA structure.

In sum, *Junk DNA* is not junk – but you have to sift through the bric-a-brac to find the treasures.

■■□□□

MUN KEAT LOOI is a science journalist with a background in genetics. He is co-author of *The Big Questions In Science*

MEET THE AUTHOR

Nessa Carey

If only 2 per cent of our DNA codes for proteins, what is the other 98 per cent – the 'junk DNA' – doing?

At one point it was thought that it was mainly just insulation, padding the important bits of our genome so that if cancer-causing mutations happened, they'd hopefully happen in the less vital bits. But we now realise that junk DNA has been co-opted for lots of other purposes, from fundamental things such as making sure that chromosomes don't unravel at their ends, to more subtle effects. Junk DNA carries out a huge range of functions.

How do scientists investigate the functions of junk DNA?

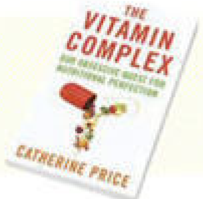
Lots of conditions are caused by changes in junk DNA, so these have helped us explore what junk DNA does. These include intellectual disability and severe muscle wasting diseases, as well as more benign conditions. Ernest Hemingway had a cat with six toes on its front paws, and there's a family in the Netherlands where the people have six fingers. Both of these are caused by a single mutation in junk DNA that changes the expression of a key gene involved in hand development.

Given that junk DNA is clearly not junk at all, do you think it's time we came up with a new name?

It really is. I think one of the problems we face as biologists is that once we give something a name, we tend to get constrained by what that name means, and then we just end up arguing about it. I think if we can come up with a different name, that'd be quite liberating for people's views on the topic.

MORE ON THE PODCAST

Listen to the full interview with Nessa Carey at sciencefocus.com/podcasts



The Vitamin Complex

Catherine Price

Oneworld P £11.99

CATHERINE PRICE BEGINS her engaging book about vitamins with the story of William Stark, a young English doctor who decided in 1769 to put himself on a series of incredibly restrictive diets.

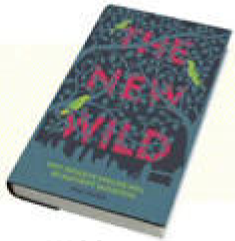
He started by eating nothing but bread, water and sugar. After a few months his gums turned black and a "disagreeable, fetid, yellowish fluid" built up in his mouth. He added cheese and honey pudding to his diet, but soon became feverish and bedridden. On 23 February 1770 he died, probably of scurvy, at the age of 29.

Price illustrates that, despite all we have learnt since Stark's death, when it comes to vitamins and nutrition "we remain surprisingly naïve". This is particularly true when it comes to vitamin supplements. The fact that vitamin D supplements are often made from lanolin – the greasy substance in wool that keeps sheep dry – was a surprise to me.

The medical consensus is that most of us don't need to supplement. Yet many people's diets are so limited that it is only the fact that some processed foods are enriched with artificial vitamins that stops us following Dr Stark's fate. This book makes a compelling case for the importance of eating real food.

■■■■□

MICHAEL MOSLEY is a BBC science presenter and broadcaster



The New Wild

Fred Pearce

Icon Books H £16.99

WHETHER THEY WASH up on islands or hitch a lift in a bird's gut, alien species have always found ingenious ways to gatecrash ecosystems. Humans have accelerated the process. In this excellent book, Fred Pearce charts everything, including botanists who took plants around the globe and oil tankers that carry marine life in their bilge tanks.

The figure quoted for dealing with 'alien invasive species' is an eye-watering $1.4 trillion. But how is that cost calculated? Pearce takes aim at a raft of statistics and finds they simply don't stand up to scrutiny. In fact, this book suggests that very few alien species do any real damage: most either die out or end up playing a beneficial part in their adoptive ecosystems. Even some of the worst horror stories, such as cane toads in Australia, actually find their own balance within a relatively short time frame.

In an era of climate change, ecological damage and habitat loss, these feisty immigrants might be our best bet of boosting biodiversity. Conservation has a long track record of backing losers, and it might be time to start backing some winners – the very aliens who bring dynamism to struggling ecosystems.

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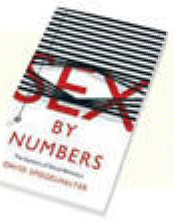
MATT SWAINE is the editor of *BBC Wildlife* and previously worked on *Lonely Planet*



Sex By Numbers

David Spiegelhalter

Profile Books P £12.99

SEX BY NUMBERS brings to life "the human elements behind the statistics".

The book teems with eyebrow-raising numbers, which have been verified by the strongest statistical tools in academia's arsenal. Genetic samples have demonstrated that 1 in 30 people have been unknowingly raised by men who are not their biological fathers. 'Paternal discrepancy' – the polite term for cuckolding – accounts for 3.5 per cent of the UK population.

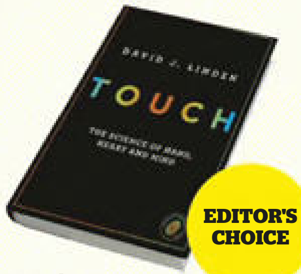
Other stats highlight the ways in which humans view the act itself: 55 per cent of the US population did not think that Bill Clinton 'had sex' with Monica Lewinsky. Sex, from this point of view, involves vaginal penetration. By inference, the majority of Americans do not believe that lesbian couples truly 'have sex'.

Human stories are brought to life too, such as the occasion a gay man met his twin, whom he did not know existed, at a gay bar. Studies of twins raised apart have taught us a great deal about the environmental and genetic factors that influence which gender you prefer.

Are statistics numbers, devoid of personality? Not at all. They just need to be described in the right way.

■■■■□

ZOE CORMIER is a science writer. Her first book is *Sex, Drugs And Rock 'N' Roll*



EDITOR'S CHOICE

Touch:

The Science Of Hand, Heart And Mind

David J Linden

Viking H £17.99

WHEN NEUROSCIENTIST DAVID Linden was a teenager, he and his friends sat around a fire asking each other hypothetical questions. One concerned the senses – if you had to live with just one sense, which would you save? Sight and hearing were popular; no one chose touch.

Like Linden's friends, most of us take the tactile senses for granted. You won't after reading this book. We learn about the skin receptors and nerve fibres that convey signals to the brain. We also find out how social and emotional context affects the brain's interpretation of these signals, and the importance of tactile contact for infant development. Linden investigates conditions that leave people in chronic pain, and the lives of those who feel no pain.

Linden delights in explaining poor masturbatory technique in terms of the 'caress sensors'. He also grosses us out with the story of a woman whose itch was so bad she scratched through to her brain. The best science writers infect you with their fascination for the subject – that's exactly what Linden achieves here.

■■■■■

CHRISTIAN JARRETT is a psychology writer and author of *Great Myths Of The Brain*

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One could also wear it on the Tube to stay cool on a hot day. To burn calories, the vest should be worn when you are sedentary, in a room at comfortable temperature. If you are exercising, or in a hot environment, the vest can help to keep you cool but will not burn excess calories.

Contact: **INFO@COLDSH.COM**
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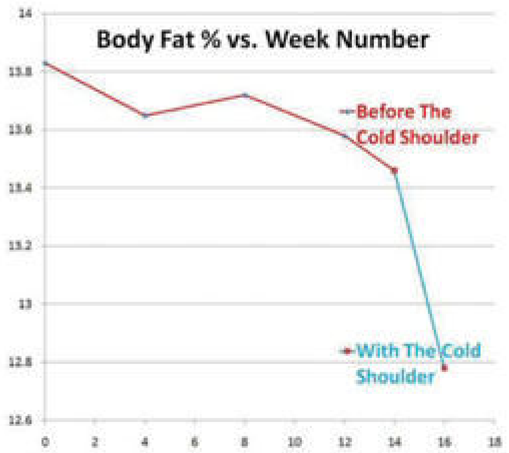

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Dr. Wayne B. Hayes wearing the vest.

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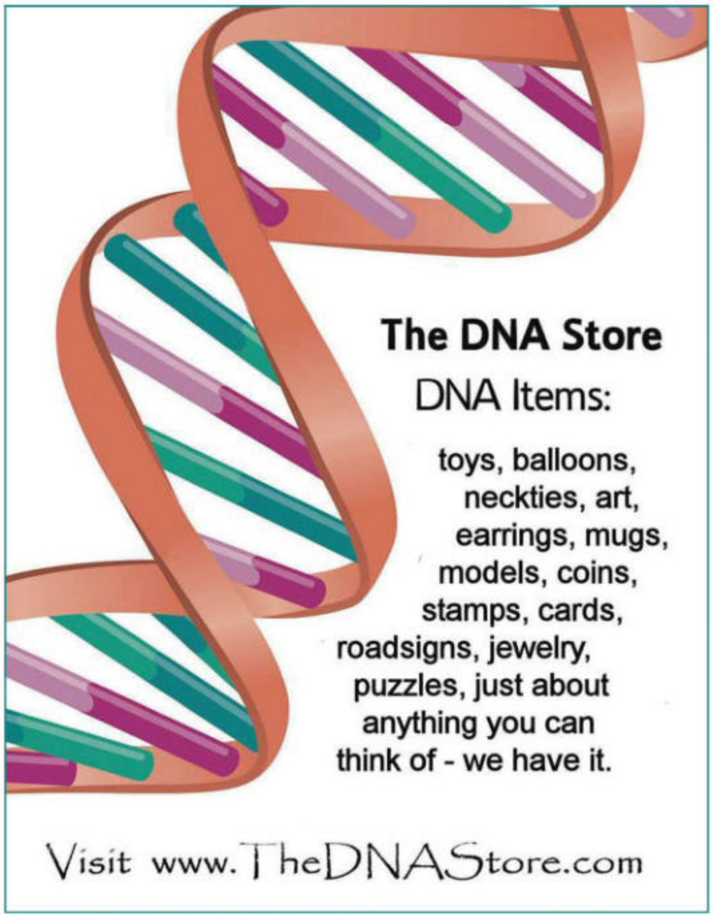

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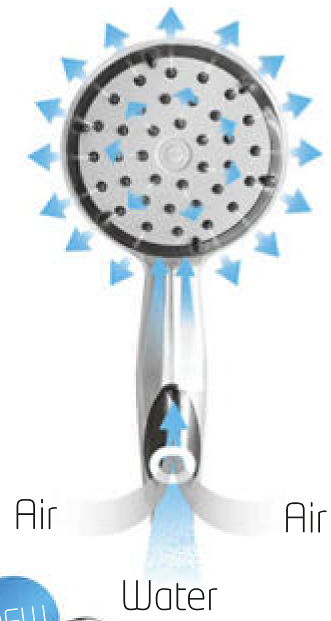

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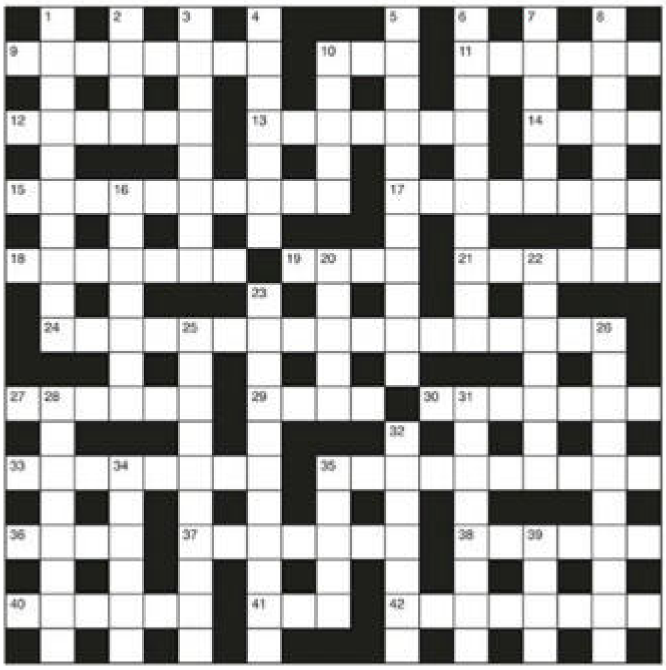
FOCUS CROSSWORD No 176

More online Solve puzzles from BBC's *Only Connect* hosted by Victoria Coren Mitchell at **http://bbc.in/1vCOzuY**



ACROSS

9 Teardrop shed by hunter (8)
10 Proverbially busy flier (3)
11 A copper gives soldiers insight (6)
12 Martin travelling in province (6)
13 Flat sadly gets car to crash, a recurring pattern (7)
14 Copy a cradle (4)
15 Search out sin, somehow burning (10)
17 Islands nowadays in series (8)
18 Woman with child in brick construction (7)
19 Measure breathing apparatus (4)
21 Left with one pound to get a drink (6)
24 Infantile treatment for an adult (10,7)
27 Nomad boat takes era to turn round (6)
29 Cooked omelettes with ancient people (4)
30 Weep about getting tune wrong for a long time (7)
33 Boasting shows bad manners at the table (8)
35 Returned with meat and game (10)
36 Leaving with a king of Mercia (4)
37 Ring with information on some elements (7)
38 Sodium turned into a race (6)
40 A drama about some ships (6)
41 Mogul moping around city (3)
42 Old toy clog sent round to obstetrics (8)

DOWN

1 Arbours not affected by huge creature (10)
2 Echo-location – not the first of the month (4)
3 It's a more refined spray (8)
4 Hard work, having to judge some plants (7)
5 Delicate nut recipe for the finely-toothed (11)
6 Value a cell that's split into furrows (10)
7 Awful craving about axes (6)
8 Bone found in ale gives one a disease (8)
10 Thinker in underwear at home (5)
16 British lumberjack is a modern diarist (7)
20 Rio lost by knockout to a tree (5)
22 Smallest amount of physics (7)
23 Snake to rile slug about fungus (11)
25 Local inhabitant to malign hen's hybrid (10)
26 Unknown boar variety is not even to hand (10)
28 Caught in costume like a hook (8)
31 Point to mad genius with compliance in selective breeding (8)
32 Managed at once to get iodine from plant (7)
34 Brawl about a scarf (6)
35 Noble woman returning mug and keys (5)
39 One of the vital cosmetics (4)

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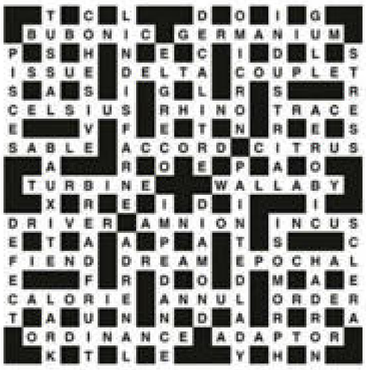
Post entries to *BBC Focus Magazine*, May 2015 Crossword, PO Box 501, Leicester, LE94 0AA or email a scan of the completed crossword or a list of answers to may2015@focuscomps.co.uk by 5pm on 30 April 2015. Entrants must supply name, address and phone number. Immediate Media, publisher of *BBC Focus Magazine*, may contact you with details of our products and services or to undertake research. Please write 'Do Not Contact' on your email or postal entry if you do not want to receive such information by post or phone. Please write your email address on your postal entry if you would like to receive such information by email.

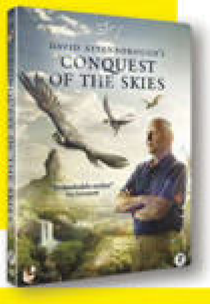
SOLUTION TO CROSSWORD No 173

Celia Fukes, Trudi Needham, Ian Glenn, Alan Pyatt and John Talbot each solved issue 277's puzzle and receive a copy of *The History Of Air Travel: From Zeppelin To Concorde* (Go Entertain, £14.99).



WIN! DAVID ATTENBOROUGH'S CONQUEST OF THE SKIES

The first five correct solutions drawn will each win a copy of *David Attenborough's Conquest Of The Skies* (Sky, £14). Entries must be received by 5pm on 30 April 2015. See below for more details.



TERMS & CONDITIONS

Entrants must be UK residents (inc Channel Islands) aged 18 or over. Immediate Media employees are not eligible to enter. By entering participants agree to be bound by these terms and conditions and that their name and county may be released if they win. Only one entry permitted per person. No responsibility is accepted for lost, delayed, ineligible or fraudulent entries. Entries received after the closing date will not be considered. Immediate Media (publisher of *BBC Focus*) will only ever use personal details for the purposes of administering this competition unless you permit otherwise. Read more about the Immediate Privacy Policy at www.immediatemedia.co.uk/privacy-policy. The winning entrants will be the first correct entries drawn at random after the closing time. The prize and number of winners will be as shown above. The winners will be notified within 30 days of the closing date by post. Immediate Media's decision is final and no further correspondence relating to the competition will be entered into. If the winner cannot be contacted within one month of the closing date, Immediate Media reserves the right to offer the prize to a runner-up.

HOLLYWOOD SCIENCE

In *The Voices*, Jerry's cat encourages him to kill, while his dog is the good guy

Communicating with dogs in The Voices

LAST YEAR, I made my dog wear a Christmas jumper. He wore it resentfully, before extricating himself from it, Houdini-style, and burying it in the garden. It's as if he was trying to tell me something. In this month's film, *The Voices*, man and dog go one step further. They actually talk to one another. But to what extent do we share meaningful communication with our mutts?

Some dogs clearly understand more than others. Chaser, a 10-year-old border collie, not only knows the names of over 1,000 different objects, but also seems to have a basic grasp of grammar. As well as simple two-word commands, Chaser also responds to more complex sentences.

Her genius is a result of intensive training from her retired psychologist owner, and raw talent. "There are some remarkable dogs out there," says Juliane Kaminski from Portsmouth University's Canine Cognition Centre. "But critics still argue how much these dogs actually understand and how much they are simply responding to previously learned associations."

> **"The world is awash with stories of Lassie-esque mutts who saved their owners"**

Dogs are, however, indisputably brilliant at interpreting non-verbal cues. Dogs, Kaminski has shown, intuitively 'get it' when a person points to a hidden treat and they use the information to retrieve the reward. To comprehend pointing, Kaminski argues, dogs must have an understanding about the perspective and knowledge of others. I knew it; my dog *does* understand me. But does he talk to me… apart from in my head?

The world is awash with stories of Lassie-esque mutts who saved their owners from peril by 'telling' someone they were in danger. Such claims are impossible to verify, so Kaminski is interested in whether dogs can communicate by pointing. She set up an experiment where a dog watched a person play with a toy, then dropped it on the floor and left the room. A stranger then entered and hid the toy, before the original person came back and started looking for it. Would the dog, who had watched the whole scenario unfold, point to or guide the person to the missing object? Man's best friend? Of course he did.

But here's the rub. Kaminski found that if the squeaky toy was replaced with something of little doggie value, such as a pair of scissors, the mutt had no interest in 'talking to us'. In this situation at least, dogs communicate with us only when there's something in it for them. Bad news if you want to discuss current affairs, but good news if you're looking for tips on how to pee on lamp posts. ■

HELEN PILCHER is a science writer and comedian. She tweets from @Helenpilcher1

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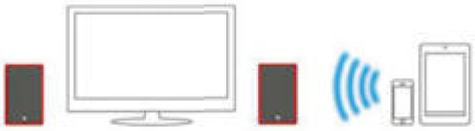

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